

**Teachers' Guide to
PHYSICS IS FUN
Books One and Two**

BY JIM JARDINE

PHYSICS IS FUN

An introductory secondary school course

Volume One

Volume Two

Volume Three

Volume Four

Teachers' Guide to
PHYSICS IS FUN
Books One and Two

JENNY TRESISE

Monks Park School, Bristol

DAVID MUIR

Forrester Secondary School, Edinburgh

DOUGLAS McMAHON

Daniel Stewart's College, Edinburgh

J. RICHARD BARR

Adviser in Science, Edinburgh Corporation



HEINEMANN EDUCATIONAL BOOKS LTD : LONDON

Heinemann Educational Books Ltd

London Melbourne Toronto Johannesburg Singapore

Auckland Ibadan Hong Kong Nairobi

S B N 435 67480 3

© Jenny Tresise, David Muir, Douglas McMahon, J. Richard Barr, 1967

First published 1967

Reprinted 1968

Published by

Heinemann Educational Books Ltd

48 Charles Street, London W1X 8AH

Printed in Great Britain by Morrison and Gibb Ltd

London and Edinburgh

Preface

This book is a guide to *Physics is Fun* Books 1 and 2 by Jim Jardine, written for courses based on the Alternative Physics Syllabus of the Scottish Education Department. The purpose of the guide is to assist teachers using the text, and it is recommended that it should not be made available to pupils.

The intention of the authors is to set out as clearly as possible the general aim and purpose of each chapter of the text in relation to the development of the course, and to indicate the relative importance of the material treated.

For each chapter, information on experimental work is given, as well as a complete list of answers to questions in the text. The answer given is not necessarily that required from pupils, as in many cases additional information is provided for the teacher.

Many new items of equipment, particularly kits of apparatus, are now available as a result of the Nuffield Foundation's Physics Teaching Project, and it is pointed out where these may be used to advantage in the experimental work. Some additional references to sources of supply, particularly items approved by the Nuffield Project, are also given.

Frequent reference is made to the texts specifically mentioned in the introduction to the S.E.D. Circular 490 as giving 'insight into the spirit and method of presentation', where teachers may find a more detailed commentary on the material discussed. Teachers are strongly urged to study those publications:

ROGERS, E. M., *Physics for the Inquiring Mind* (London: Oxford University Press, 1960).

PHYSICAL SCIENCE STUDY COMMITTEE, *Physics* (Boston: D. C. Heath, Second Ed., 1965).¹

¹ References given are to the first edition, 1960.

Note on the Organisation of the Guide

Physics is Fun, by Jim Jardine, is a complete course in physics for secondary schools published by Heinemann Educational Books Ltd in four volumes.

The chapter and section numbers in this Guide tally with those in the appropriate Pupils' Book. Each chapter is divided as follows:

(a) Introduction.

(b) 'Experimental Work', which covers the experiments, demonstrations, and models numbered thus, 11.3, consecutively within chapters and printed in red in the Pupils' Books.

(c) 'Answers to Questions', which gives the answers to the questions printed in black italics and numbered thus, (2), consecutively within chapters of the Pupils' Books.

Nuffield Apparatus

The references to Nuffield apparatus given thus, (N.12), refer to the catalogue numbers in the *List of Nuffield Apparatus*.

Contents

Preface	v
Note on the Organisation of the Guide	vii
The study of physics	xv
Some features of the teaching method	xvii
Important experiments	xxv

book one

Introduction	xxix
---------------------	------

Chapter 1—Measurement

Introduction	1
Experimental work	1
Answers to questions	2

Chapter 2—Our place in the universe

Introduction	4
Experimental work	4
Answers to questions	5

Chapter 3—The solar system

Introduction	7
Experimental work	7
Answers to questions	9

Chapter 4—Matter—its forms and changes

Introduction	11
Experimental work	12
Answers to questions	13

Chapter 5—Molecules

Introduction	15
Experimental work	16
Answers to questions	20

Chapter 6—Atoms

Introduction	22
Experimental work	22
Answers to questions	23

Chapter 7—Measuring matter

Introduction	25
Experimental work	25
Answers to questions	25

Chapter 8—Weighing matter

Introduction	28
Experimental work	28
Answers to questions	28

Chapter 9—Squeezing and stretching matter

Introduction	31
Experimental work	31
Answers to questions	34

Chapter 10—Heating matter

Introduction	39
Experimental work	39
Answers to questions	42

Chapter 11—Push-push. Pull-pull

Introduction	44
Experimental work	46
Answers to questions	51

Chapter 12—Turn. Twist. Topple

Introduction	54
Experimental work	54
Answers to questions	56

Chapter 13—Work—work—work

Introduction	59
Experimental work	61
Answers to questions	63

book two

Teachers' introduction to the guide to book two	67
---	----

Chapter 1—Fluid flow

Introduction	69
Experimental work	69
Answers to questions	74

Chapter 2—Flow of electric charges

Introduction	76
Experimental work	77
Answers to questions	86

Chapter 3—Flow of heat

Introduction	88
Experimental work	88
Answers to questions	93

Chapter 4—Waves

Introduction	94
Experimental work	94
Answers to questions	97

Chapter 5—Sound waves

Introduction	98
Experimental work	98
Answers to questions	102

Chapter 6—Electro-magnetic radiation

Introduction	106
Experimental work	106
Answers to questions	107

Chapter 7—The visible spectrum

Introduction	109
Experimental work	109
Answers to questions	115

Chapter 8—Infra-red radiation

Experimental work	118
Answers to questions	119

Chapter 9—Electron pumps

Introduction	120
Experimental work	120
Answers to questions	121

Chapter 10—A vicious circle

Introduction	122
Experimental work	122
Answers to questions	125

Chapter 11—Cells

Introduction	128
Experimental work	128
Answers to questions	130

Chapter 12—Magnetic magic

Introduction	131
Experimental work	131
Answers to questions	133

Chapter 13—Canned currents

Introduction	134
Experimental work	134
Answers to questions	140

Chapter 14—Electro-magnetism

Introduction	141
Experimental work	141
Answers to questions	146

‘From the point of view of basic physics, the most interesting phenomena are of course in the *new* places, the places where the rules do not work—not the places where they *do* work! That is the way in which we discover new rules.’

Richard P. Feynman, *Lectures on Physics*, Vol. I, 2-2. (Addison-Wesley, London, 1963.)

The Study of Physics

In Book One of the text, pupils are introduced to a vast range of natural phenomena and to the means of understanding them. Pupils study large and small scale properties of matter, and forces, motion and energy, which constitutes the mechanics of material bodies. Book Two, which concludes the first cycle of 'physics for all', introduces flow, wave motion and electricity.

We must strive to put within the grasp of our pupils, through reasoning and understanding, the means of investigating, altering and controlling their physical environment by the techniques of scientific investigation. We must look to these pupils to produce, or at least to live with, the new discoveries and the technology of ten or twenty years hence.

We may think of physics either as the theoretical and experimental study of time, space, matter, motion and electricity; or may define physics operationally in terms of what is being currently investigated in research and in industry. However we regard the study of physics, it may be well to recall at the outset of any course that what has motivated and absorbed the physicists in the past, in unravelling the complexities and mysteries of nature, is the same spirit of investigation and discovery which prompts the teacher to devise his or her own demonstration, or the pupil to take his school experiment a stage further than his limited instructions. If we can prompt our pupils to suggest, devise and construct as well as describe and explain, and make available to them the situation in which they become sufficiently interested and absorbed to start thinking on their own, and raising their own questions, then they may feel their own way to a real understanding.

Difficulties in the Study of Physics

It has become apparent from teaching the course that once initial difficulties of the supply and organisation of equipment are overcome, the main difficulty lies in the understanding by the pupils, at such an early age, of the abstract ideas and concepts. Apart from the obviously abstract nature of kinetic theory and atomic structure, such concepts—familiar to the teacher—as molecule, ion, electron, force, motion and energy are only vague names to the pupil, unless we allow them to make their own abstractions from the concrete experience of experimental work, and build their own visual and tangible models of our theories. This is a very difficult task in teaching

physics. We must try to lead pupils to see for themselves that our observations, our questions and our experimental conclusions can be built into a simplifying pattern or concept which encompasses what we know now and what we have yet to encounter, and to see some regularity, some symmetry, or even some analogy, in what appear at first sight disconnected phenomena and events. We shall not succeed in this task by simply telling them, or by offering grandiose explanations and elaborate theories, but we have to encourage them to evolve their own mental picture from what they experience.

In this task of making our concepts real, we rely heavily on analogues and models; models of the solar system, the atom, crystal structure and thermal conduction, as well as models, in the more common sense, for mechanics—model steam engines, internal combustion engines and electric motors. We use analogues for the particle (photon) model of optical reflection, and wave analogues for the interference, refraction and polarization of electromagnetic waves, as well as analogues for Millikan's experiment and radioactive decay. All of these are used with the intention of giving greater reality to the intangible entities with which we deal so freely in modern physics.

However unless the pupils are able to experiment freely themselves, to see the purpose of good demonstrations, to have time to develop their own ideas and suggest their own models, we shall not be teaching our pupils physics but simply telling them about physics and so our teaching methods are to be of vital importance.

Some Features of Teaching Method

'Operational' Approach

We cannot expect that subtle concepts, such as inertia, momentum and energy, which have taken many years to evolve, can be appreciated and understood by pupils as soon as they are introduced. We encourage pupils to investigate their own experiments as fully as time allows, and then to build up, little by little, their own ideas from the evidence before them. We must be prepared for the lengthy process of gradually developing ideas by way of explanation of observed facts. We adopt an operational approach.

Concepts such as weight, temperature, molecules, can be mentioned and illustrated experimentally before any attempt is made to define them. Once the idea has germinated in the mind of the pupil it can be elaborated upon and refined.

Take, for example, the 'kinetic model of matter'. Pupils will be familiar with the words 'atom' and 'molecule' from popular usage, so that when they are searching for an 'explanation' of their observations on, say, crystals, we can discuss how these 'molecules' might be arranged—even though the pupils have only a very elementary concept of a molecule.

That molecules of a gas are constantly moving seems an idea alien to most pupils. However, confronted with the evidence of diffusion or Brownian motion, pupils soon have to modify their ideas of 'static balls' and so the basis for our kinetic theory is formed. A working model can then predict certain relationships between, for example, pressure and volume. Later work will involve more sophisticated formulations of ideas which we must allow to germinate in the mind of the young pupil—e.g. Boyle's law, and an algebraic treatment of kinetic theory.

It has often been suggested that many of the difficulties encountered by our senior pupils stem from lack of familiarity with fundamental concepts. This can only be remedied by carrying out many simple experiments as suggested above.

Concentric Methods

The whole course is designed on a concentric development.¹ The 'physics for all' of Books One and Two is followed by a second more

¹ For a further example of this an A.S.E. Publication, *An Expansion and Teachers' Guide to Physics for Grammar Schools*, pp. 6, 7.

quantitative cycle in Books Three and Four, aiming at a greater depth of treatment. For example, after a brief look at molecular motion via Brownian motion in the first year, we return to introduce the molecular kinetic theory of gases in the third year, and are able to offer an explanation of Boyle's law. The ideas of moving molecules lead in the second year to ideas of moving ions in electrolytes and electrons in solid conductors, and in the fourth year to moving streams of electrons *in vacuo* as our introduction to electron physics and electronics. The concept of energy, introduced tentatively in first year mechanics, provides another thread linking such topics as the propagation of energy by waves in the second year. We return again in the cycle to transformations of potential and kinetic energy studied quantitatively in the third year, and yet again to electrical and finally atomic and nuclear energy in the fourth year. Concepts such as energy, flow and waves serve to link our progress throughout the course and avoid the arbitrary division into mechanics, heat, optics and electricity.

Experimental Methods

Experiments form the backbone of the course, and the methods which we employ to guide pupils in their experimental work are extremely important. Once the general problem has been posed for some investigation, any instructions given should be strictly limited to leave the whole planning and procedure as 'open' as possible, although the desired end may have to be carefully engineered by providing the necessary groundwork and suggestion. We should, when possible, give pupils scope to organise and plan out their experimental procedures, to devise their own arrangements of the apparatus and to express their own observations and conclusions. If we hope to give our pupils, in two years, some indication as to how physicists work and conduct research, we certainly shall *not* plan to present them with a step by step detailed set of instructions for each experiment. It is vital to allow each pupil to find his own way to the formulation and solution of a problem.

Apart from pupil experiments with some desired conclusion, there is an important place in the course for experiments which simply let pupils see the phenomena for themselves.

There is also a place for good demonstrations, which may be more effective than unconvincing pupil experiments. One well-planned demonstration can cover enough ground to allow time for open experiments in other appropriate parts of the course.

Mathematical Methods

Right from the start of our physics course we employ a range of magnitudes, from the nuclear diameter 10^{-10}m to the diameter of the galaxy, 10^{21}m —a range which staggers the imagination!

The pupils must somehow acquire an appreciation of order of magnitude, and be equipped with an index notation to handle this. It is not, however, suggested that these methods should be taught formally, but every opportunity should be taken for their use, particularly in blackboard exposition, until pupils feel familiar with them and have the confidence to use them themselves.

In experimental work we cannot go far, especially if we wish to avoid tedious arithmetic, unless our pupils learn to make valid approximations, to write significant figures only, to appreciate the accuracy of their results and to learn that there is no 'right' answer but only a result within the limit of their experimental procedure.

Although we may be satisfied if first year pupils appreciate that an oil monolayer indicates only a finite limit to the size of a molecule, a simple quantitative calculation to indicate the order of magnitude will give a greater reality to our theories. Pupils remain unconvinced of the many abstract ideas and concepts unless they are led to appreciate that 'rough' methods, such as the one above, give valid results.

One difficulty of teaching modern physics is that our ideas are often based on the cumulative results of many *indirect* methods of measurement, which we as physicists have been conditioned to accept, combined with a vast body of knowledge at a level beyond the comprehension of our pupils. If we start in the first year asking how we time a *single* swing of a pendulum, measure the thickness of a sheet of paper using only a ruler, or determine the spacing of the grooves in an L.P. record—and emphasise the *indirect* nature of this procedure, we may find the pupil is better prepared to progress to the sophisticated methods required of him.

If we are to teach physics, as opposed to teaching *about* physics, we need the vital techniques of quantitative study which are the backbone of physics. We need our supporting theories and formulae derived from them in order to obtain tables of results which we interpret in the form of graphs or mathematical relationships. We require functional relationships, such as that between force and extension for a spring, and proportional relationships as in Newton's and Boyle's laws. However, throughout we must keep the emphasis on understanding, and on interpretation of formulae, not the mathematics or formulae themselves.

Much of modern physics is concerned with the elements of probability and statistics. We could in the third year introduce and

illustrate the random walk applied to Brownian motion studies, but in the fourth year we find it is essential to consider in some detail the statistical and random nature of radioactive decay.

We also require some consideration of the idea of calibration. This can be introduced early in the course—calibration of a simple type of balance, of a thermometer and of a pressure gauge. We come to the need for calibrating current balances, ammeters and voltmeters in the fourth year.

Throughout physics we are beset by many systems of units, and although S.I. units have been adopted as standard, much literature still appears in other systems.

An important technique, which is well worth the trouble of teaching, is that of working through the units, as well as the figures, in a calculation. This provides a useful check on the dimensions of the answers.¹

Pupil's Records

Some attention must be given to the problem of the pupil's own record of his work, since the formal (and often dictated) presentations are usually inappropriate here.

There are many occasions on which the pupil will benefit most if he is encouraged *not* to make any notes at all. Pupils' own descriptions of what they think they have seen in their first session with ripple tanks often include faulty observation, misuse of such words as 'reflection', ambiguous statements like 'We saw wide and narrow lines at once'. Such records are obviously misleading, and once an incorrect statement is committed to paper, it is extremely difficult to erase it from the pupil's mind. Taking notes at the same time as experimenting can easily detract from thoroughness and certainly interferes with progress.

When we feel that a record of an experiment should be kept, perhaps to help recall in the future, encourage the pupil to try different techniques of recording and after a while allow him to choose his own method.

1. A straightforward description is time-consuming and tedious to produce. It is seldom the most efficient form of recording an experiment in the early stages.

2. A quick diagram of apparatus used, if necessary labelled, is often sufficient, for example the microbalance (Fig. 1).

3. A graph or histogram may be adequate. If a suitable title is given there may be no need to give an account as well, for example stretching a spring (Fig. 2).

4. A table which can be built up gradually is a method of recording

¹ See *Physics for the Inquiring Mind*, *op. cit.*, p. 514.

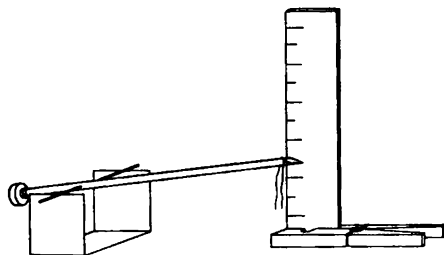


FIG. 1

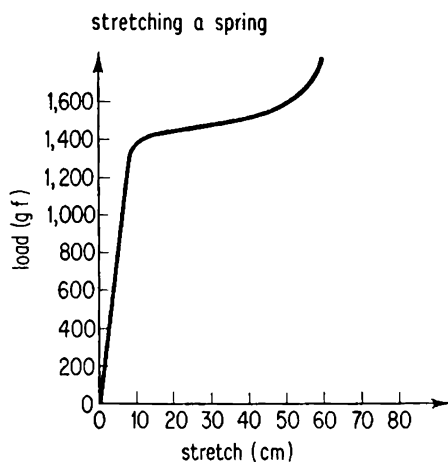


FIG. 2

which should help pupils to see some overall pattern to a set of experiments.

(a) Conclusions from experiments are seen at a glance, for example in the study of the behaviour of matter (Fig. 3).

<i>Property</i>	<i>Solid</i>	<i>Liquid</i>	<i>Gas</i>
Density	●	●	•
Expansion with heating	•	●	●
Compression	•	•	●
Change of state		little change in volume →	big change in volume →

FIG. 3

(Size of spot indicates relative magnitude of property)

xxii PHYSICS IS FUN TEACHERS' GUIDE

(b) Similarities between different experiments, and the ideas involved, are obvious, e.g. in the study of flow (Fig. 4).

	<i>Fluid flow</i>	<i>Heat flow</i>	<i>Electrical flow</i>
Gradient			
Section increased	faster rate	faster rate	more current
Length increased	slower rate	slower rate	less current

FIG. 4

(c) Differentiating between two distinct concepts, for example, force and energy, is made easy (Fig. 5).

Lever 	Force Transformer. (Can use small force to balance large one.)
	But not <i>energy</i> multiplier. (Must push small force through large distance. $\therefore E_y$ never less than Lx .)

FIG. 5

(d) Results are recorded without emphasising experimental method (Fig. 6).

See Nuffield booklet *Physics Testing and Examinations* also *General Introduction to Nuffield Teachers' Guide I*.

Formulation of Questions

Questions in the text are designed to start pupils thinking about the material, or to test understanding. Questions asked in class and set in examinations reflect the methods employed in teaching.

A few specific points may be noted. Questions are more valuable if designed to make pupils think rather than remember, so that they are encouraged to develop a sense of reasoning in a scientific way. As well as introducing questions by the words 'describe' and 'explain', we can also use 'suggest' and 'propose', which may require

DENSITIES

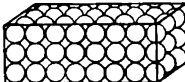
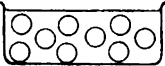
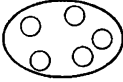
solid	liquid	gas
 Aluminium 2.5 g/cm^3 Lead 11 g/cm^3 etc.	 Water 1 g/cm^3 Mercury 13.6 g/cm^3 Meths. 0.8 g/cm^3 etc.	 Air 0.001 g/cm^3 etc.

FIG. 6

initiative on the part of the pupil. Theories, some possibly absurd, can form a convenient starting point for good discussion.¹

On the other hand, some rethinking about answers to questions would not be amiss. Since in the light of our modern knowledge very few answers can be regarded as complete or final, we must be content with a satisfactory depth of answer to meet the situation encountered.

¹ Cf. *Physics for the Inquiring Mind*, *op. cit.*, Chapter 24, for 'Plogglies and Demons'.

Important Experiments in the First and Second Year

To a teacher planning a series of physics lessons based on the Scottish syllabus, Books One and Two offer such a large number of experiments that it is obvious that only a selection from them would be suitable.

What experiments are included depends to a large extent on the apparatus available, the special interests of the teacher and those of a particular class. It is worth reminding ourselves that the pupils who drop physics after two years will probably forget most of the actual experiments before they leave school. We can but hope that they take with them into their adult lives some real understanding of a few basic principles, and an idea of what science is and how scientists set about investigating problems.

Care must be taken also in dividing the time among pupil experiments, demonstrations and class discussions.

BOOK ONE

Introduction (pp. 1-5)

Introduction

This section may be regarded as a brief introduction to scientific method. Both the introduction and first chapter of the text discuss topics fundamental for the later development of the course. These should be returned to, for further consideration, again and again throughout the course and the ideas discussed gradually refined. However, it may not be desirable, particularly with the less able pupils, to introduce Physics in this manner. Consideration of scientific method and techniques of measurement will be all the more valuable if, after some experimental work has been done, the need for such discussion is felt as a result of the pupil's own experiences; the need for the right questions to be asked before tackling an experiment; for some theory to explain their conclusions and for systematic methods in conducting experiments, making measurements and assessing the accuracy of results.

A diagrammatic summary (Fig. 7) showing the cyclic development of physical investigation may be all that is necessary for pupils to record at this stage:

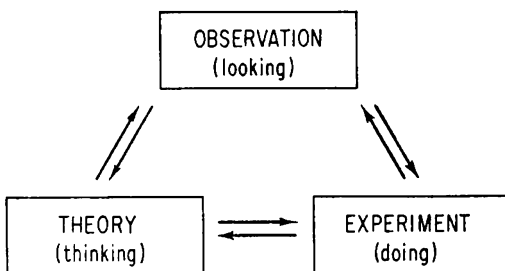


FIG. 7

A single lesson based on this introduction would be all that time allows.

Experimental Work

A good introductory experiment, which encompasses all the essentials of a good physics lesson, can be initiated by giving pupils a simple form of pendulum to play with—say a length of thread stuck to a marble with Sellotape, or a length of string tied to a large nut—(if the string is looped with a clove hitch round the rod of a retort

stand clamp, this allows for easy adjustment of the length). Ask for any observations; suggestions for timing—particularly how to find the time for a single swing to and fro, i.e. the periodic time of the motion; suggestions for any quantities we might vary—length, mass of bob and angle of swing; any conclusions as to what might be valuable and useful knowledge.

Here we have an introduction to experimental methods, to relationships of variable quantities and to the concept of periodic motion.

Notes. (i) It could be of interest to show that the periodic time could be measured directly with the bob interrupting light beams to two photocells connected to an electric stop clock or scaler.

(ii) A single photocell could be used to operate a Post Office type counter and count the number of swings mechanically—these could be arranged concurrently as a demonstration and illustrate the use of modern electronic techniques.

(iii) Many extensions of this experiment are possible,¹ e.g. 'thought experiments' to consider two equal pendulums swinging together and the effect of joining the bobs with a thread, then sticking the bobs together to double mass of bob (Fig. 8) or the extension of the length and arc to approach in the limit to free fall (Fig. 9).

(iv) A 'seconds' pendulum (period 2s, length 99.5 cm) might well be made and used later for timing.

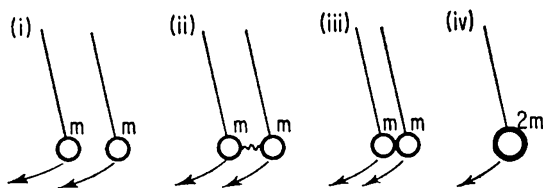


FIG. 8

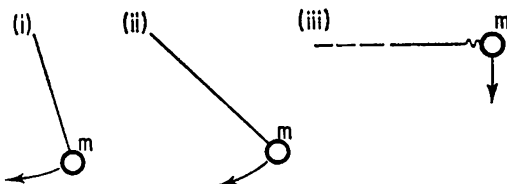


FIG. 9

¹ ROGERS, *op. cit.*, p. 66, Experiment D, Pendulums; p. 275. Galileo's Mechanics of Motion.

P.S.S.C. Text, p. 4. P.S.S.C. Lab. Guide, III-1, A Variation on Galileo's Experiment.

ANSWERS TO QUESTIONS

1. Iron ships float; iron a shirt; iron out a difficulty; clap in irons; iron grip; a No. 3 iron; the iron road.

2. Because of the pull of gravity.

We rather accept the fact that forces produce motion as a basic premiss contained in our definition from *ma*.

3. Newton, Sir Isaac (1642–1727).

4. Using our pulse beat which we assume to be regular (cf. Rogers, p. 275), or counting as ‘one—and—two—and—three—’

It may serve as a reminder that our ‘sense of time’ is rather inaccurate if pupils are asked to close their eyes and then put their hands up after they think, say 30 sec, 1 min, — 3 min, have passed. This of course shows less accuracy over longer intervals of time.

5. (i) Mass of bob.

(ii) Angle at which pendulum is released.

(iii) Effect of air friction.

(iv) Effect of neighbouring bodies (not near Schiehallion)

6. Time of swing increases.

7. Length is proportional to the square of the time.

Pupils should be able to spot the relationship from the figures given in the text if figures only are copied in two adjacent columns on the blackboard. No algebraic formulae or graphs would be appropriate at this stage but the opportunity should be taken of investigating simple numerical relationships between physical variables; since this is of the essence of physical method (for a good discussion of proportionality see Rogers, pp. 198–203).

8. Simply explains ‘how’ the pendulum behaves.

Why it does so requires consideration of the forces acting and the solution of the equation of motion.

9. French *des* (= Latin *dis*) negative, *astre*—a star.

10. Strictly no.

Only by measuring a very large number of triangles and obtaining the same result within the limits of error of our measurement—this is the *physical* method of proof. The *mathematical* result is an abstraction based on a logical argument from certain postulates.

I Measurement (pp. 6–11)

Introduction

The techniques of measurement discussed in this chapter, accuracy, estimation, averages and approximation, are fundamental throughout the course, just as the mathematical concepts of ratio and proportion briefly mentioned in the introduction. However, any introduction to these ideas at this stage should be limited and practical, the intention being mainly to refer pupils back to these topics as the need arises. Any prolonged discussion at this stage would stifle rather than stimulate interest.

The concept of a light year as a measure of distance appeals to imaginative pupils and a notation using powers of ten enables them to deal with simple problems, makes more concrete the magnitudes involved and later enables them to cope with the whole range of modern physics from galaxies to nuclei. Again, facility with this notation and the necessary rules for manipulating indices will only come at a later stage and should not be laboured here.

Scale drawings¹ serve a most useful purpose if they give us a visual impression of relative distances and sizes. Again a brief mention where appropriate.

A single lesson based on a selection of these topics would be sufficient.

Only Experiment 1.2 is really of value.

This raises an important point in making a simple measurement, namely, that there is no 'correct' result in the arithmetic sense but only a measurement valid to the accuracy of our measuring instruments (for background reading see Rogers, Ch. 11 and *P.S.S.C.* Text, Ch. 2, 3 and 4–4).

Experimental Work

Experiment 1.1. This could be useful as ideas of scale are used in Nuffield biology as well as in physics. Many suitable blocks are contained in Nuffield Kits—Materials Kit (N.1).

Experiment 1.2. Pupils should be set to carry out a simple measurement, such as suggested—measuring the length of a bench is very suitable.

This appears so 'obviously' easy for them until they are beset by

¹ Cf. *P.S.S.C.* Text, p. 45, 'Scaling, The Physics of Lilliput'.

practical difficulties in actually trying it; particularly how best to determine where the 'end' of the bench is, how to allow for chalk marks (~ 0.5 cm wide) or pencil marks (~ 0.5 mm wide), how to keep metre sticks in line, allow for undulations of the bench surface, etc.

A possible demonstration which is instructive is as follows¹: several metre sticks are necessary to stretch along the bench giving the integral number of units. For the fractional part one metre stick is specially marked 100 cm and another cut into 50 cm, 10 cm, 5 cm, and 1 cm lengths so marked (1×50 cm, 1×20 cm, 2×10 cm, 1×5 cm, 2×2 cm, 1×1 cm lengths if desired).

We can then proceed to show how we arrive at a closer and closer approximation to the fractional part of the length. We can fit the fractions, making the *decision* as to whether they are too great or too small, just as in the system of obtaining a balance point with chemical balance weights. We gradually refine the accuracy of our measurement, giving smaller and smaller limits within which the length lies. This makes the process of decision involved clear, and gives a precise meaning to what we are doing when we measure the last fraction with an ordinary metre stick.

Nuffield suggests the use of centimetre scales without the millimetre graduations, and these are useful in making practical estimates to the nearest mm (instead of one-tenth of a mm as with the normal school ruler) and for making valid approximations (N.25).

ANSWERS TO QUESTIONS

1. Method will not give accurate results if faces of cube are not plane or if angles are not right angles.

2. 2.22 in or 2.23 in.

3. Not justified.

4. Between 2.2215 and 2.2225.

5. 324.1 cm and perhaps 420 cm.

6. Other results differ in units, this result in hundreds. 420 cm: fairly far out.

7. 425.13 cm and 423.16 cm.

8. 425.1 cm and 423.2 cm.

9. 425 cm, 424 cm, 420 cm, 423 cm. Should be written 425.0 cm, etc.

10. 424.9 cm the arithmetic average of the results, omitting 324.1 cm and 420 cm. Taking 324.1 cm as 424.1 cm an obvious error in transcription. Note that accuracy implied from text results is much greater (0.1%) than would normally be expected in school work where an accuracy of 1% or even 5% is regarded as satisfactory.

¹ P.S.S.C., Text, Ch. 10-11, pp. 168-9.

11. Scientists currently concerned with time and frequency standards.¹

12. 23 462 784 million miles. 1 light year = 5 865 696 000 000 miles. Rather take 1 light year = 6×10^{12} mi giving required distance as 24×10^{12} or 2.4×10^{13} mi. Other problems can be devised taking $c = 3 \times 10^8$ m/s.

13. 600.

14. One only.

15-16.

700.0 =	7.00×100	$= 7.00 \times 10^2$	7.00×10^2	7.0×10^2	7×10^2
280.00 =	2.80×100	$= 2.80 \times 10^2$	2.80×10^2	2.8×10^2	3×10^2
4 960 =	$496 \times 1 000$	$= 4.96 \times 10^3$	4.96×10^3	5.0×10^3	5×10^3
8 247 000 =	$8.247 \times 1 000 000$	$= 8.247 \times 10^6$	8.25×10^6	8.3×10^6	8×10^6
15 060 =	$1.506 \times 10 000$	$= 1.506 \times 10^4$	1.51×10^4	1.5×10^4	2×10^4
92 520 =	$9.252 \times 10 000$	$= 9.252 \times 10^4$	9.25×10^4	9.3×10^4	9×10^4
1 600 000 =	$1.60 \times 1 000 000$	$= 1.60 \times 10^6$	1.60×10^6	1.6×10^6	2×10^6
186 000 =	$1.86 \times 100 000$	$= 1.86 \times 10^5$	1.86×10^5	1.9×10^5	2×10^5

17. Most have no built-in scale—depends also on depth of field and angle. Where precise measurements have to be made from photographs, e.g. from cloud chamber, stereoscopic cameras are used.

18. Aerial map.

19. Ordnance Survey Map compiled by triangulation.

20. 8.4 in.

21. Edinburgh to Kirkcaldy (via Kincardine) 50 mi.

22. Edinburgh to Kirkcaldy (via Forth Road Bridge) 25 mi.

23. 0.008 in.

24. 25 in to 1 mi.

25. No.

On A.A. Atlas scale road is about 500 ft wide.

¹ N.P.L. *Units and Standards of Measurement I* (D.S.I.R., H.M.S.O. 1962), p. 5.

2 Our Place in the Universe (pp. 12–17)

Introduction

Tom Swift,
Colinton Road,
Edinburgh,
Scotland,
Earth,
Solar System,
Milky Way Galaxy,
Universe.

Most pupils have speculated in this way about their place in the Universe. The purpose of this chapter is to give a more definite idea of our location in space and to stimulate interest in our astronomical neighbourhood.

None of the experiments here can be regarded as essential and after a brief lesson to arouse some interest, possibly annotated with film strips, this chapter could be left as home reading.

Experimental Work

Experiment 2.1. This is not particularly easy to perform due to the use of sodium vapour lamps for street lighting in our towns. The results of such an experiment are shown in Rogers, p. 214, *P.S.S.C. Text*, Ch. 22, p. 344.

Experiment 2.2. Pupils should be encouraged to try making a simple telescope. The use of a tube as holder for the lenses presents difficulties.

It is much easier to use a straight lath of wood to which are screwed a large and small size Terry clip as lens holders (N.115). A watchmaker's eyeglass makes a convenient eyepiece.

Most pupils are interested in the fact that astronomical refracting telescopes produce an inverted image; this of course must be taken into consideration when showing photographs of, say, the Moon (Rogers, p. 280).

It is also fairly easy to construct a model of a Newtonian reflecting telescope.

It is of interest here to mention that Galileo first observed the moons of Jupiter using a very simple telescope (*P.S.S.C. Text*, p. 1).

Experiment 2.3. It may be well to point out that the eccentricity of

the Earth's orbit is very small (-0.017) (cf. Rogers, pp. 267-8, for a scale drawing of this).

Experiment 2.4. This is currently of interest in connection with the motion of artificial satellites as well as the motion of the planets and many more elaborate versions of this experiment are possible. (Cf. *P.S.S.C. Lab. Guide*, III-6, Centripetal Force; and Rogers, p. 300).

Mention should also be made of Newton's drawing from his *System of the World* representing the velocities necessary for orbital motion (*P.I.F.*, Book Three, p. 55, and Rogers, p. 332).

ANSWERS TO QUESTIONS

1. By drawing an imaginary line through the last two stars—the pointers—of the constellation of the Great Bear or the Plough (Ursa Major), and following this direction some way until a star of second magnitude is observed at the tail of the Little Bear (Ursa Minor).

Here pupils could be encouraged to make and carry about with them in the evenings a small stiff card showing say the Plough or Orion, to help in recognition of this and other constellations. These cards can be easily made by drawing on a postcard the outline of the constellation, marking the positions of the stars and pricking through the card at these points with a pin. When held up to a street light the shape of the constellation can be seen (Fig. 10).

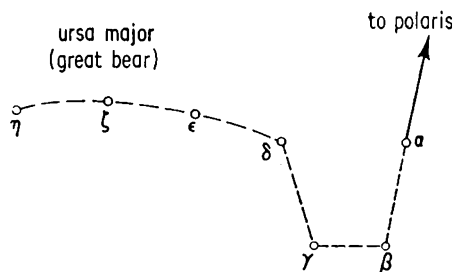


FIG. 10

2. The Sun. Mean distance 9.3×10^7 miles or 1.497×10^{11} m.

3. Because of very high temperature and fluid nature of surface.

Temperature at the surface is about 6×10^3 deg C and at centre is computed to be about 3×10^7 deg C. The radiation flux is 6.25 kW from each square centimetre of surface or 3.8×10^{26} W from entire surface. This energy comes from fusion of light nuclei in a thermonuclear process.¹

¹ GAMOW, G., *The Birth and Death of the Sun* (London: Mentor Books, 1956, p. 100).

4. Estimated to be over one hundred billion (10^{14}) stars forming a lens shape approximately 10^6 light years in diameter and 2×10^4 light years thick.

5. Planets, asteroids, comets, galaxies, radio sources and quasars.

6. Planets are relatively cool and only seen by reflected light from the sun. Asteroids are minor planets in a belt between Mars and Jupiter. Comets mostly consist of empty space with a little gas and dust distributed through them, and rendered visible by the light of the sun. Halley's Comet last appeared in 1910 and should reappear in 1986. Radiation pressure causes the 'tail' of a comet to point away from the sun.

Galaxies are great clusters of stars usually spiral in shape. Radio sources emit electromagnetic waves of radio wavelengths and may be exploding galaxies. Quasi-stellar radio sources are about one hundred times brighter optically than the brightest known galaxies and about ten thousand times smaller and are still unexplained.

7. Planets move or 'wander' amongst the fixed stars.

8. Greek *planetes* 'a wanderer'.

9-10. The ellipse approaches a circle in the limit when the two pins coincide.

11. Perihelion—point of nearest approach to the sun.

12. Most early satellites moved in ellipses with a period of about 100 minutes.

13. Perigee 150 mi for the early satellites, and apogee 200-500 mi.

The Tiros weather satellites were sent up in almost circular orbits varying from 429-468 mi. The first Early Bird communications satellite launched in 1965 was put in a fixed position over the equator at an altitude of 22,300 mi in such a position as to make it synchronous with the rotation of the Earth.

14. Most recent British instrumented satellite was Ariel II in 1964.

15. Force of gravitational attraction.

16. Escape velocity from Moon is 1.5 mi/s compared with 7 mi/s for the Earth.

3 The Solar System (pp. 18-30)

Introduction

Having glanced briefly at the outer reaches of the universe this chapter returns to have a closer look at the solar system and our own planet Earth. To obtain some indication of relative size of Earth and Moon we require large-scale measuring techniques, which must of necessity be indirect, and to visualise we need models. The chapter closes with a look at the Earth's interior and atmosphere.

Although these topics may lead at a later stage to a closer study of planetary astronomy,¹ celestial dynamics and analogies with orbital models of the atom, probably all that time will allow at this stage is again a brief lesson, with the object of stimulating interest, leaving this chapter as home reading. A demonstration and discussion of a simple Earth-Moon model using a film-strip projector as the Sun would suffice.

It should be noted at this stage that the temptation to linger on this part of the work, as it is undoubtedly of great interest to pupils, should be resisted as the main part of the course is yet to come.

Experimental Work

Experiment 3.1. Many interesting observations can be made by simply placing a retort stand on a large sheet of drawing paper at a south-facing window when it is sunny. If a large semicircle is drawn on the paper with radius equal to the initial length of the shadow, and a set of lines drawn parallel to the diameter, the angular movement and the length of the shadow at say hourly intervals can be recorded. Local noon can be determined, either by noting when the shadow is shortest, or by bisecting the angle formed by the initial position of the shadow and the position when it again touches the arc.

Experiment 3.2. Pupils can be set the problem of finding the distance to objects, such as a retort stand, on a neighbouring bench without crossing the intervening space. Two protractors laid flat on pieces of wood and a supply of optical pins to sight along should suffice for this. Otherwise an optical range finder could be calibrated and used for this purpose (cf. *P.S.S.C. Lab. Guide*, I-2).

¹ ROGERS, Part Two, *op. cit.*, 'Astronomy—A History of Theory'.

Experiment 3.3. Both the Sun and Moon subtend an angle of about 30 minutes of arc at the Earth so that a coin held at about arm's length can be made to coincide with either (for a discussion of this see Rogers, p. 233).

Lunar diameter is about 2,162 miles as against Earth's diameter of 7,920 miles. Solar diameter is approximately 8×10^5 mi.

Experiment 3.4. Scale diagrams are given in *P.S.S.C.* Text, p. 352 and p. 351.

Model 3.5. An old tennis ball, preferably painted white, with a knitting needle stuck through it, and into a large cork bung as a base, makes a very satisfactory model of the Earth. A smaller ball, such as a table tennis ball, can be mounted on a wire support to represent the moon (Model 3·7) (Fig. 11).

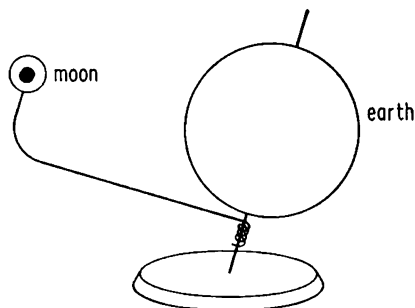


FIG. 11

Many elaborate orrerys can be constructed but are not necessary here. If of interest, the following references to the *School Science Review* will provide details:

(i) An Earth-Moon-Sun orrery, *S.S.R.*, No. 163, p. 839 (June 1966).

(ii) Construction of an orrery, *S.S.R.*, No. 155, p. 229 (November 1963).

(iii) A conic section orrery, *S.S.R.*, No. 157, p. 634 (June 1964).

(iv) Machines for showing s.h.m.; Kepler motion and the apparent (Ptolemaic) motion of planets, *S.S.R.*, No. 158, p. 147 (November 1964).

Experiment 3.6. The cosine law is of such frequent occurrence in later work that this could well be mentioned and also the falling away of intensity with distance (inverse square law) (cf. Rogers, p. 317).

Experiment 3.7. Note particularly that the shadow traces out a broad band over the Earth's surface within which the eclipse seen would be total.

Experiment 3.8. It is almost essential for the room to be dark and the ball to be painted white for this to be seen.

ANSWERS TO QUESTIONS

1. Many recent photographs taken from orbiting space vehicles show the curved surface of the Earth (cf. *P.S.S.C. Text*, p. 102).

Discussion of the evidence for a round earth given by Rogers, p. 230.

2. At X Sun would be on horizon so shadow very long.

At Y Sun directly overhead so no shadow.

Cf. How Eratosthenes measured the size of the Earth (Rogers, p. 234).

3. Use a builder's plumb-line.

4. Use a joiner's spirit-level.

5. Angle of 90° .

6. Circumference 25 700 mi.

7. Height 72 ft.

8. Mercury, Venus, Earth, Mars.

9. Because of greater contrast, since reflected light is reduced to a minimum.

10. 24 hr.

11. One half of the day.

12. No.

Axis should be tilted to plane of orbit at $23\frac{1}{2}^\circ$.

13. 365.256 days. One sidereal year.

14. From the model, (a) would be of equal length.

15. From the model, (b) would be at same height.

16. From the model, (c) would be the same.

17. No.

This should be obvious to pupils from above considerations.

18. When direction of the beam is at right angles to the paper.

19. When plane of paper is parallel to direction of the beam.

20. On the Equator.

21. At X.

22. A Summer, B Spring, C Winter, D Autumn.

23. Mean lunar month is 29.531 days.

24. Neap tides occur when Sun and Moon pull at right angles to one another (cf. *Reed's Nautical Almanac*, published annually, for 'An Explanation of the Tides').

10 PHYSICS IS FUN TEACHERS' GUIDE

25. See diagram (Fig. 12).

26. See diagrams (Fig. 13).

27-28. Both within the thickness of a pencil line.

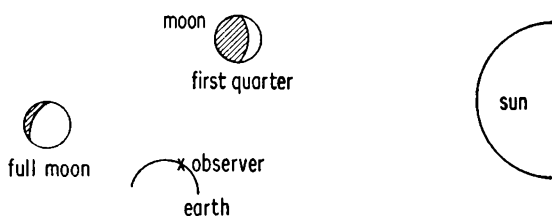


FIG. 12

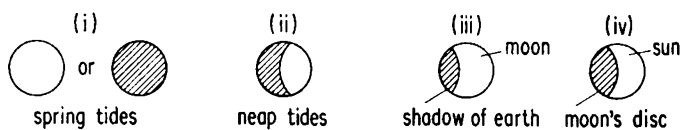


FIG. 13

4 Matter—Its Form and Changes (pp. 31–35)

Introduction

In this chapter we introduce the pupil to a simple study of the various forms that matter can take, the states of matter, physical changes from these states and also the phenomena of magnetising and electrifying matter. We illustrate the manner in which we can change matter by subjecting it to various forces, contact forces—push, pull, twist and stretch; gravitational forces and the forces of electricity and magnetism. We subject matter to heat and study comparative expansions, we compress gases and note the large changes in volume produced. Only as the pupil becomes aware of the complexity of these properties and feels their reality in the course of experiment do the questions naturally arise which require explanation in terms of what occurs in the micro-world of matter. We must explain the characteristic densities of substances, comparative expansion of solid, liquid and gas, relative changes in volume in melting and in boiling. For this we need concepts of molecular structure of molecular motion, of inter molecular forces and thermal agitation.

It is important that pupils should become aware of the vastness of the subject which they are studying—and this awareness should come early in their experience in the laboratory.

We must therefore select a sufficient number of varied experiments to illustrate as many physical changes as we can. We hope to awaken and stimulate that spirit of enquiry into all branches of physics which will help pupils to a mature appreciation of their own experimenting, discussions, conclusions, theories, and of the work of other physicists. There is ample opportunity for pupil investigation here, and during their observation of physical changes we must encourage them to ponder about what might be happening to the materials they are investigating, e.g. as substances melt, or burn in a flame. Even if no ideas are formulated into words, we shall need considered opinions when discussing the work of Chapters 5 and 6 later. Heat will play an important part in our physics course, so the sooner we can stimulate such questions as ‘What on earth *is* heat?’ or ‘What does heat *do* to matter?’ the better will the pupils be prepared for the following sections. The work on change of state and thermal expansion must not be neglected.

Since we shall not be very concerned with chemical changes in this course, we need not spend much time on them, but a few spectacular

demonstrations might promote helpful questions about 'what's going on'.

Nuclear changes must be included because of their importance in modern physics, but will not occupy much time in class.

This chapter might occupy two lessons.

Experimental Work

Experiment 4.1. Pupils should be encouraged to speculate on the fate of the heat supplied to the melting ice and boiling water.

Experiment 4.2 (a) (1). Freeze a thermometer into an ice cube in a refrigerator—or use a freezing mixture. Then record the temperature at which the ice falls from the thermometer.

(a) (2). Warm the naphthalene gently in a test tube with a Bunsen flame—beware of spitting. Since naphthalene is crystalline it has a well-defined melting point, 80°C .

(a) (3). Use a water bath as paraffin wax is inflammable. Since it is amorphous, paraffin wax melts over a range of temperatures 38°C to 56°C .

If pupils are already familiar with graphs, they might be encouraged to represent their findings graphically.

(b) (1), (2). Salt solution freezes at a lower temperature, and boils at a higher temperature than water.

Use solid carbon dioxide to freeze salty water.

Demonstration 4.3 (a). Sublimation occurs—a change from solid direct to vapour.

Demonstration 4.4. The iodine will not melt, but sublimation occurs at temperatures lower than the melting point. As the vapour can be 'poured out' its density is greater than that of air. (Density of iodine vapour— 11.27 g/l . Density of air— 1.29 g/l .) Solid iodine will form on the sides of the test tube as it is cooled.

Demonstration 4.5. A 'smoke' of minute fragments of Metafuel is formed as a result of sublimation.

Experiment 4.7. See Nuffield Year II *Teachers' Guide to Experiments and Apparatus*. Class Experiment 71 (Fig. 14).

Experiment 4.8. Salt.

Experiment 4.9. Alnico is an alloy of aluminium, nickel and cobalt. The magnetized needle will pick up iron filings, etc. It may be

demagnetized by heating in a Bunsen flame until it is red hot, or by passing it through a coil carrying a.c.

Like poles repel and unlike poles attract each other.

Experiment 4.10. To discharge a charged insulator pass it very *quickly* through a Bunsen flame. Good results are obtained from polythene, perspex and other plastics.

Demonstration 4.11. A polythene rod rubbed on a sleeve will produce a spark to the ear which can be heard easily.

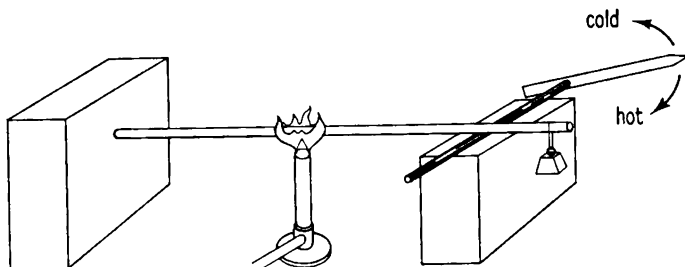


FIG. 14

Demonstration 4.12. (b) A white powder, magnesium oxide is formed.

(c) Mercury droplets can be seen. Test for oxygen with a glowing splint.

(d) This can be dangerous as it sputters.

(e) Smoke for theatricals is sometimes produced this way. The smoke is ammonium chloride.

(f) The mixture is explosive and produces a 'volcano'.

Nuffield introduces the Taylor cloud chamber at the end of the first year to illustrate nuclear changes (N.28).

ANSWERS TO QUESTIONS

1. The Latin word from which our word 'matter' is derived, 'materia', was used for 'building material', and we can think of matter as the stuff of which the world around us is built. For most purposes we can consider that anything which takes up space or has weight is 'matter'.

2. 'Potty putty' (a compound of silicon, available from Frido or Griffin & George).

Glass—old glass can be seen to have flowed, and yet it retains crystalline properties.

Plastic sulphur. If moulded it solidifies.

Pitch.

3. The hot water vapour which comes out of the spout of the kettle is invisible—hence the gap. It is only when the vapour has condensed in the cool air that it is visible as tiny water droplets—steam.

4. The word 'steam' is used to describe the water vapour (gas) *and* the mist of condensed droplets (liquid).

5. Water vapour does not condense into water droplets on a hot surface.

6. (i) Boiling point.

7. When anti-freeze is added to water the freezing point of the solution is lower than that of water, i.e. the solution will not freeze until its temperature falls well below 0°C .

8. The temperature is not likely to fall so far below 0°C that the solution in a car battery, petrol or oil will freeze.

9. Mercury.

10. Where ever the normal temperature is below 0°C , e.g. Arctic regions.

11. Some molecules from the moth-balls escape into the air and affect our organs of smell—the solid evaporates.

12. A compass needle is a piece of magnetized material, pivoted so that it can swing in a magnetic field.

13. The end of a bar magnet which is called 'the north pole' is that end which swings towards the earth's North pole, i.e. it is the north-seeking end of the magnet.

5 Molecules (pp. 36–46)

Introduction

This is an extremely important chapter and may take the better part of a term if it is to be treated thoroughly and without undue haste. However, this will be time well spent if the spade-work has been done and the foundations laid for constructing our kinetic model of gases which is treated more solemnly later. We shall need to refer again and again to the ideas formulated here—so that we must do all we can to ensure that this work is clear.

Work on crystals should not be hurried. We must make sure that there are enough microscopes for pupils to use without undue hold-up and frustration, and that there is a wide variety of small crystals and powders for them to examine. Large crystal models will be especially useful for reference in group discussion.

Brownian motion is such an important piece of experimental evidence for the particulate nature of matter that we should ensure that every pupil studies it well. Our follow-up with macroscopic models must be clear so that we are not confronted with confused pupils who talk of 'smoke molecules'.

Some diffusion experiments must be shown to back up our theory that molecules are in motion—and that molecules of different materials move at different rates.

Pupils will need to know of the spaces between molecules, and they should have an idea of the size of molecules.

Here we require a careful approach for we are entering an intangible world. We need all our resources—we need to introduce hypotheses, to suggest theories and make models; but above all we require effective pupil experiments, and convincing demonstrations. We must show clearly, and take time over, Brownian motion, diffusion, crystal growth, transparency of gold leaf, oil monolayers and cloud chamber tracks, let pupils hear the click of a Geiger counter, before we can hope for any conviction or sense of reality. This is the exciting stage where our pupils should get the opportunity to suggest, devise and construct their own theories and models and build their own picture of the micro world.

Demonstrations 5.12 to 5.15 serve as a valuable introduction to the important and exciting measurement of the size of a molecule. Any teacher tempted to cut short this preparation must carefully consider the importance of understanding the method and calculation

used in D. 5.16, so that we do not lose by the wayside confused pupils who cannot see the wood for the trees.

In the Nuffield Physics Project, every pupil does his *own* experiment to find the height of an oil molecule.

Models are important tools of the physicist. We hope to show in the years ahead, just how powerful a tool the kinetic model is—it predicts pressure changes when volumes are changed, it gives us an idea of what 'heat' might be. It can be used to calculate the speed of molecules, molecular diameters, and so forth. But we must be honest enough to modify any model when necessary, and to scrap it when it no longer fits observed facts.

The question of forces between molecules will have been discussed already by many pupils, so that the experiments to demonstrate this need not take up much time.

Experimental Work

Experiment 5.1. These are useful experiments which can be done at home.

(a) The source of sound cannot always be located easily.

(b) If the smell of the pear is strong enough, the apple will taste like pear. (Onion is an effective substitute for pear.)

(c) A burning sensation is often reported. It is sometimes difficult to distinguish between the sensations of extreme heat and extreme cold. If a finger is placed on the 'cold spot' at the back of the neck the finger will feel warm relative to the spot, even if the cold spot originally felt warm.

(d) The outer edges of the two fingers do not often simultaneously feel the *same* object so that it often seems that there are two noses.

(e) The hand which was in the hot water feels cold and the other hand feels hot.

(f) The finger appears to point to different spots.

Experiment 5.2. (a) Crystals have regular shapes characteristic of the substance.

(e) In all fragments, most of the faces have the same slope as in the original crystal.

(f) This is difficult but with patience ice crystals can be seen forming.

An observant pupil should notice that no matter what size a crystal is, it has smooth sides, sharp angles at interfaces, and that these interfacial angles are characteristic of a particular crystal. 'Damaged' crystals also exhibit these properties to some extent, but it is worth while selecting suitable crystals.

See also *Nuffield Teachers' Guide to Experiments and Apparatus*

Year I. Experiments 3D to 12b. (N.3)—crystal kit. Film: *Crystals*, P.S.S.C. made by Alan Holden.

ALAN HOLDEN, *Crystals and Crystal Growing* (Science Study Series) (London: Heinemann Educational Books).

Experiment 5.3. (a) Notice that the larger droplets of oil (from milk) suspended in water 'dance' less rapidly than their smaller neighbours.

(b) See *Nuffield Teachers' Guide to Experiments and Apparatus*. Experiments 49 to 55). (N.29)—smoke cells.

Model 5.4. (b) The Nuffield kinetic theory model kits are useful here. (N.12)—marbles in tray.
(N.11)—three-dimensional model.

Demonstration 5.5. As the mercury molecules are heated, they evaporate more quickly into the vacuum above. These rising molecules have sufficient momentum (large mass, speed increased with heating) to knock the small balls upwards. (The motion of the balls is controlled by gravity too so that this is not a true picture of Brownian motion.)

Demonstration 5.6. (a) Hydrogen will bubble through the water since hydrogen diffuses in through the porous pot more rapidly than air diffuses out. (Air having more massive molecules is more 'sluggish'.)

(b) As air molecules leave the porous pot more quickly than the carbon dioxide molecules enter, the water *rises* in the tube (Fig. 15).

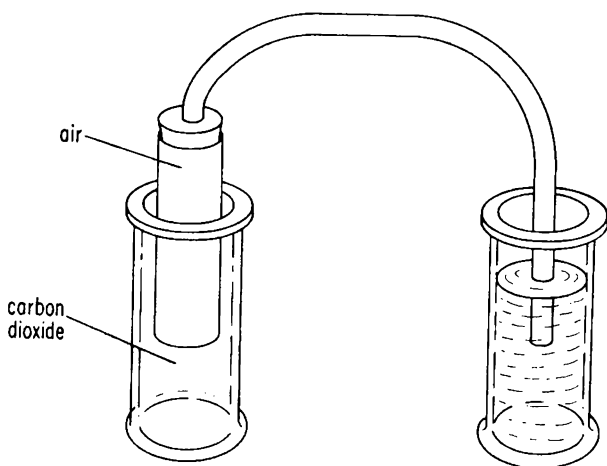


FIG. 15

Experiment 5.26. When close together the pieces of cork move together because of the surface forces in the water.

ANSWERS TO QUESTIONS

1. All three figures are about the same height.
2. When the moon is near the horizon it appears to be larger than when it is high in the sky.
3. Hold a pencil at arm's length as shown and with one eye closed move your finger along the pencil until the projecting end of the pencil subtends the same angle at your eye as does the moon (Fig. 16). Mark the pencil so that you can repeat the experiment when the moon is in various positions.

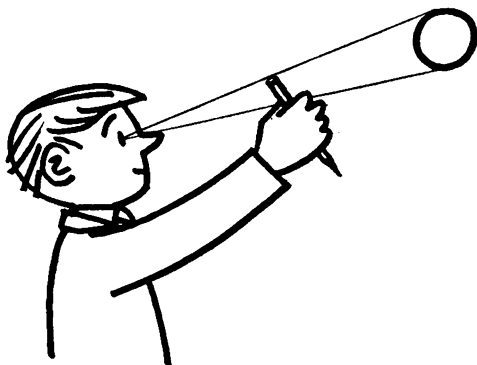


FIG. 16

4. Taking into account the hoard of everyday experience as well as those we gained in preceding experiments, (a) and (c) are rather harsh criticisms of our senses, (b) is sensibly cautious.
5. Investigate with (a) A radio receiver.
(b) A compass needle.
(c) A Geiger counter.
6. We hope you wouldn't just SAY something, but SHOW him as many effects as possible which you would attribute to air, e.g. air resistance as you pull a sheet of paper through it (see *Nuffield Year I Teachers' Guide*, Ch. 6). For electricity, turn on lights, fire, iron, etc., or give him an electric shock with a small induction coil!
7. We can 'explain' the regular slopes of crystals if we consider them to be formed from tiny identical 'building blocks', each block composed of 'pieces of matter' packed in certain ways characteristic of that material.
8. The molecules must be moving much faster than the solid specks.

9. The speck would not move at all.

10. Air molecules ARE able to swim through the holes in the porous pot, but air molecules do not move as quickly as the hydrogen molecules.

11. Carbon dioxide molecules are even slower than air molecules in getting through.

12. Hydrogen molecules move more quickly than air molecules. Carbon dioxide molecules move more slowly than air molecules.

13. There are spaces between the molecules in a liquid and in a gas.

14. 'Kinetic' means 'something to do with movement' (from Greek *kinesis*, motion).

15. Cohesion is generally strongest in solids.

16. (a) The strength of materials, hardness, elasticity, bubbles, drops.

(b) Friction between 2 surfaces, drops of water on glass, etc., glues, lubricants, etc.

17. Drops of molten lead are dropped through a tall tower. Surface tension forces cause the drops to become spherical and in transit these spheres solidify.

18. Surface tension forces tend to make the surface area of a liquid as small as possible. (The sphere has the smallest $\frac{\text{surface area}}{\text{volume}}$ ratio of any solid.)

6 Atoms (pp. 47–55)

Introduction

It is obviously very important that pupils should not be worried by our use of unfamiliar words such as 'electron'. However, we shall need it in our vocabulary before long, so we must engineer classroom conditions so that pupils are calling out for a theory into which we can introduce 'the electron'.

After the work outlined in Chapter 5, pupils should be confident of the molecular structure of matter, but as yet there has been no necessity to postulate the existence of sub-atomic particles. The simple electrostatics experiments therefore play an important role in the development of our atomic model.

Radioactivity has for too long been treated as a difficult academic subject, suitable only for study by advanced students. However, it must not be regarded as an optional extra in this part of the course. Having established the idea of sub-atomic particles, we must continue to sub-nuclear particles. From popular literature, films and television, pupils will have heard something of nuclear particles. We owe it to them to offer all the evidence we can muster for such particles. It is important, too, that pupils should not feel that they now have all the answers to queries about 'fundamental particles'.

Experimental Work

Experiment 6.2. Calcite is included in the Nuffield Crystal Kit (N.3) for cleavage.

Experiment 6.3. Such materials are available in Nuffield Malvern Electro-statics Kit (N.51).

(a) Polythene strips repel each other as both are negatively charged.

(b) Both are positively charged and repel each other.

(c) The strips attract each other.

(d) As no third type of charge can be found which will repel the two charged rods we assume that only two kinds of electric charge exist.

Demonstration 6.4. Each of the charged rods will cause the electro-scope leaves to diverge. When the rods are held together the two equal charges cancel so that the leaves do not diverge.

A much better pupil experiment is illustrated in Fig. 17.

A duster is wrapped around an uncharged polythene rod and pushed into a calorimeter placed on an electroscope. The leaves are together showing that there is no charge. Pull the rod out quickly so that the rod is charged (negative) and the duster is charged (positive). The leaves will diverge. Now replace the rod and the leaves will come together showing that the charges were equal in magnitude and opposite in sign.

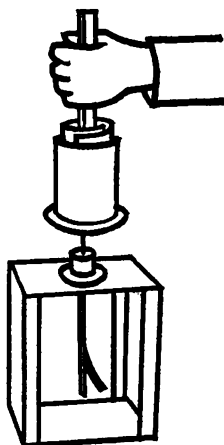


FIG. 17

Experiment 6.5. The leaves collapse.

Experiment 6.6. A shadow of the washer will be produced on the film.

Experiment 6.9. An alpha particle consists of two protons and two neutrons.

In the Nuffield Physics Project small Taylor cloud chambers, (N.28), are provided for pupils working in groups of four.

ANSWERS TO QUESTIONS

1. Positively charged rods repel each other.
2. Negatively charged rods repel each other.
3. A positively charged body attracts a negatively charged body.
4. We expect the number of orbital electrons to be the same as the number of protons in the nucleus.
5. An alpha particle is made up of two protons and two neutrons.

6. Neutrons either have no charge, or they have equal quantities of positive and negative charge (i.e. they have no net charge).

7. An atom (as distinct from an ion) has equal quantities of positive and negative charge (i.e. it has no net charge).

8. With only background radiation, particles reach the Geiger tube at irregular time intervals.

9. They arrive in a completely random way.

7 Measuring Matter (pp. 56–60)

Introduction

With suitable preparation, this chapter can be dealt with during less than one lesson.

It is very important that pupils feel confident that their own measurements are reliable. Make sure that each pupil has practice at home in measuring lengths, calculating volumes, etc. He will then be ready to appreciate the discussions on standards for length, and will follow more comfortably blackboard calculations.

Some problems such as (15) can be set for homework after the lesson.

Make sure that all pupils see a measuring jar, a burette and a pipette in use.

Experimental Work

Experiment 7.1. Is it advisable to allow pupils to use inches, feet, etc., but they should be encouraged to use metric units as soon as possible. Later, all work will be in S.I. units.

In the Nuffield Physics Project it has been found helpful to use centimetre rules without millimetre marks. Materials kit. (N.1).

When making a displacement can it is difficult to avoid a 'lip' between the can and spout. To avoid difficulty with a head of water building up there, decrease the surface tension by adding a drop of detergent to the water used.

ANSWERS TO QUESTIONS

1. The revised standard version of *The Bible*. *Genesis* 6, 13–15 inclusive:

'And God said to Noah, ". . . This is how you are to make it: the length of the ark three hundred cubits, its breadth fifty cubits, and its height thirty cubits.'" 1 cubit $\approx$ 20 inches.

2. Barleycorns are not all the same size so that the length measured would depend on the particular barleycorns used.

3. Since metals expand on heating, the metal bar on which the standard metre is marked is kept at constant temperature. This bar is of platinum iridium because this alloy doesn't expand very much when the temperature does rise.

4. Find a ruler marked in inches and centimetres, rule a line (10 in long would be convenient) and see how many centimetres there are in this length.

5. Multiply length by breadth.

6. The area of each face of the box would be given in cm^2 and the volume in cm^3 .

7. The volume of the box.

8. 200 cm^3 , 100 cm^3 , 32 cm^3 , 800 cm^3 .

9. One would expect to give the length of the side of a brick to the nearest mm (or if the brick is very rough to nearest cm).

10. The meniscus on the surface of mercury is convex to the air.

11. See Fig. 18.

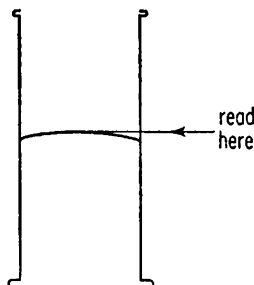


FIG. 18

12. To find the volume of a solid object using a displacement can, pour water into the can until water dribbles from the spout—into a suitably placed tin! Replace the tin by a measuring cylinder. Lower the object by string gently into the displacement can until totally immersed so that all the displaced water is caught in the measuring cylinder and read the volume of the water displaced—which is also the volume of the object.

13. In each case, the 'displacement can' method *could* be used . . . or choose a deep vessel into which the shoe, bicycle or yourself would fit and fill it with water, or suitable substitute. Mark the height of the surface of the water before and after total immersion of the object. Measurement of base-area of the vessel and a short multiplication will provide the required volume.

14. Either of the displacement methods would do, but since sugar is soluble in water, use a liquid in which sugar will not dissolve (e.g. oil) instead.

15. Use either method suggested in (13) provided a sinker is used to hold the cork below the water surface, and an ancillary experiment is carried out to find the volume of the sinker.

16. See following paragraph in the text.

17. It is easier to measure volumes than weights as a simple calibrated container is all that is required. Liquids are incompressible and adopt the shape of the container. Solids have spaces between each piece. One hundredweight of coal has a much greater apparent

volume than a hundredweight of coal dust. A displacement experiment would be need to find the real volume of a hundredweight of coal.

18. There would be more coal gas in a cubic foot at high pressure than at low pressure.

8 Weighing Matter (pp. 61–64)

Introduction

Much of this work can be done at home. It might seem sensible to allow pupils the choice of Experiment 8.1 or 8.2. It is essential that each pupil has the experience of weighing liquids and gases too, so that he has an idea of their relative densities—especially when he later discusses the spacing of molecules in solids, liquids and gases. Some calculations on density will help pupils towards a clearer implicit understanding, but there is no need to force pupils to complete all the numerical examples. However, the arithmetic involved in each example is extremely simple.

Experimental Work

Experiment 8.2. Micro balance kit. (N.4).

The straw is more stable if the needle is inserted above the widest part of the straw (above its C. of G.).

Experiment 8.3. Nuffield materials kit. (N.1).

Experiment 8.4. Density of water	= 1.0 g/cm ³ .
Density of methylated spirit	= 0.8 g/cm ³ .
Density of olive oil	= 0.9 g/cm ³ .
Density of carbon tetrachloride	= 1.6 g/cm ³ .

Experiment 8.5. If the subject is raised by pupils, buoyancy could be discussed here.

Experiment 8.6. (a) Density of air = 0.001 g/cm³.

The Nuffield Physics Project has devised a simple experiment in which air is pumped into a large plastic container, which is weighed and then the air is released into a rectangular Perspex box under water. Large plastic container and rectangular Perspex box are both in Nuffield Year I General Kit (N.1).

(b) Atmospheric pressure.

ANSWERS TO QUESTIONS

1. The mass of sugar remains the same, but the gravitational attraction (and therefore its weight) has been reduced to zero.

2. Kitchen, greengrocer shops, chemists (for weighing babies, and adults), chemistry lab., post office, railway station, airport, etc.

3. The word 'amount' can be applied to any quantity which is measurable, and even to concepts which defy measurement, e.g. amount of time, space, and amount of nonsense, thought, laughter. 'Amount' could mean mass, volume or even cost!

4. 19.3 g.

5. 19.3 g/cm³.

6. 2.5 g/cm³.

7. (a) 0.2 g.

(b) 2 g.

(c) 10 g.

8. (a) 7.5 g.

(b) 75 g.

(c) 750 g.

9. (a) 10 cm³.

(b) 55 cm³.

10. (a) 2 cm³.

(b) 10 cm³.

11. 8 g/cm³.

12. 25 g.

13. 100 cm³.

14. 40 g of cork.

15. Density of aluminium = 2.7 g/cm³.

Density of gold = 19.3 g/cm³.

16. Gold is approximately 7 times as dense as aluminium.

17. Some liquid would remain in the container, and some would probably be spilt. The balance pan might become corroded.

18. Mass of liquid $M = 30$ g.

Density of liquid $\frac{M}{V} = 0.75$ g/cm³.

Mass of liquid = 65 g.

Density of liquid = 0.65 g/cm³.

Mass of liquid = 48 g.

Volume of liquid = 32 cm³.

Density of liquid = 1.5 g/cm³.

Mass of water = 100 g.

Volume of water = 100 cm³.

Density of water = 1 g/cm³.

19. Place the displacement can and the 20 metal cubes on the balance pan (Fig. 19). Fill the displacement can to overflowing with meths using the beaker to catch the overflow. Thus find the mass of the displacement can, the meths and the cubes.

Carefully submerge the cubes so that a volume of 20 cm^3 of meths is displaced into the beaker. Note the new reading on the balance. By subtraction, the mass of the known volume of expelled meths is found, and its density can be calculated.

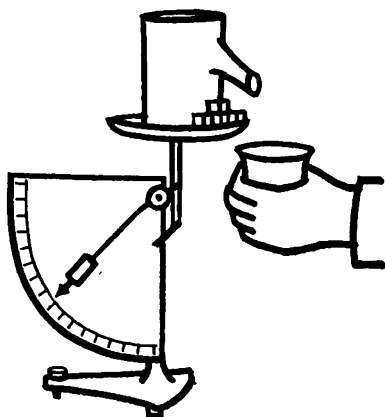


FIG. 19

9 Squeezing and Stretching Matter

(pp. 65–79)

Introduction

Our young physicists need to have a nodding acquaintance with the behaviour of different materials which are subjected to forces of various kinds. We must allow them as much opportunity for individual experimenting as possible.

The experiments on the behaviour of springs serve many purposes. First, the pupil must learn to set up his own equipment in a sensible way so that measurements are easily taken with the minimum of personal discomfort. A comfortable scientist is more likely to be a thorough one.

The pupil must design his apparatus so that he can read off (or work out) what he set out to do. He must learn to minimise erroneous effects such as clamp-stand wobble and parallax. He must record his findings so that they are legible to others, and he must find suitable ways of presenting his results, for example, in tables or graphs. We must discuss with him the possibility of drawing a straight line through points on a graph and the meaning of such a line.

Flotation is a latent problem in most young minds. Treat it informally since we seldom need it again in our physics course, but make sure pupils are no longer baffled by it.

Pressure must be investigated so that we can show our kinetic model earning its keep. There is a grand selection of experiments to show atmospheric pressure. Choose a few that you consider clearest and perhaps set one or two for homework.

The work in this chapter could well occupy 3–4 weeks.

Experimental Work

Demonstration 9.1. See *Nuffield Teachers' Guide Year I*, demonstration 36a.

Experiment 9.2. Pupils should be encouraged to investigate the behaviour of the spring past the elastic limit and on to the final breaking of the wire, so that these springs must be regarded as expendable. Let's hope that a pupil asks 'What has happened to the atoms in the spring during that experiment?' Then encourage him to examine the broken end under the microscope. Packet of 100 springs (N.2A).

The Nuffield Physics Project also suggests that pupils wind their own springs from copper wire. Reel of 32 s.w.g. bare copper wire (N.2B).

Pupil-teacher discussions should include a very elementary treatment of personal errors, and the validity and use of straight-line graphs.

Experiment 9.4. A force of 10 lbf is applied each time but the pressure is greater when the area is smaller. Distortion of the Plasticene depends on pressure.

Demonstration 9.5. Some suppliers are now making glass-backed Bourdon pressure gauges (N.67).

Demonstration 9.6. Density of carbon tetrachloride = 1.6 g/cm^3 .
Density of mercury = 13.6 g/cm^3 .

Experiment 9.7. (a) Water could settle in the position shown only if you were to close the right-hand tube (e.g. by putting your finger over it) when pouring the water into the other tube. The water pressure would then be balanced by the air pressure.

Demonstration 9.8. The head of water above the mouth of the jet in the funnel provides sufficient force for a fountain. Air resistance and friction in the nozzle prevent the water from reaching the level of the water surface in the funnel.

Experiment 9.9. (See previous comment.)

It is difficult to make sure that the jet is vertical without any wobbling or twirling. The nozzle size affects the height of the fountain, and so too will any breeze. Also, the height of the highest spray alters as the fountain plays. Water pressure is greater than 21 ft of water.

Experiment 9.10. As the can is pushed further into the water the pressure, due to the depth, increases and hence the force on the bottom of the can increases.

Experiment 9.11. If the solid floats the weight of the liquid displaced is equal to the weight of the solid.

Demonstration 9.13. Density of rubber = 1.6 g/cm^3 .
Density of carbon tetrachloride = 1.6 g/cm^3 .

Experiment 9.14. The average density of an egg is greater than

that of pure water but equal to that of the salt water in which it floats.

Experiment 9.15. For teacher's reference.

Density of mercury	= 13.6 g/cm ³ .
Density of carbon tetrachloride	= 1.6 g/cm ³ .
Density of oil	= 0.8 g/cm ³ .
Density of iron	= 7.9 g/cm ³ .
Density of rubber	= 1.6 g/cm ³ .
Density of paraffin wax	= 0.9 g/cm ³ .
Density of cork	= 0.25 g/cm ³ .

Experiment 9.16. This experiment is probably more easily done with tin foil than with Plasticene, although since Plasticene is denser it might be more convincing.

Experiment 9.17. The hard block cannot displace its own weight of water and therefore will not float. The crumpled ball is full of 'pockets' into which the water does not immediately enter, so the ball can displace a weight of water greater than the weight of the aluminium and therefore it will float.

Demonstration 9.18. Carbon tetrachloride vapour is denser than air and so forms a blanket over the liquid. Soap bubbles then float in a layer some distance above the bottom of the jar.

Experiment 9.19. In a normal bicycle pump the washer spreads out forming a seal when the handle is pushed inwards. The air is therefore compressed.

When the washer is reversed the seal is formed only when the handle is pulled outwards. This produces a region of low pressure.

A pellet is projected by high pressure air in the bicycle pump.

Experiment 9.20. The wood snaps—air pressure acting over the paper holds one end of the stick down.

Experiment 9.21. Air pressure $\simeq 14\frac{1}{2}$ lbf/in².

Demonstration 9.22. As the pressure above the rubber is greater than the pressure below it the rubber is depressed.

Experiment 9.23. The air in the bottle is used up in combustion so that the pressure of the air in the bottle is reduced sufficiently for atmospheric pressure to push the egg in through the neck of the bottle. It is sometimes difficult to keep the meths burning long

enough. An egg with the shell removed usually proves more co-operative than the vinegar-soaked shell. Some dairies now use narrow-necked bottles which are unsuitable for this experiment.

Experiment 9.24. (a) When the steam condenses the pressure inside is less than the pressure outside the can and the can collapses.

(b) The meths vapour drives the air out of the container. When the vapour condenses it leaves a lower pressure inside than outside the container.

Experiment 9.25. The fact that the balloon is approximately spherical suggests that the air pressure in it is the same in all directions.

Demonstration 9.26. The mercury in the basin takes the place of the smaller limb of the J-tube. The zero of the metre stick should be on the open surface of the mercury.

Experiment 9.27. (See Fig. 20.)

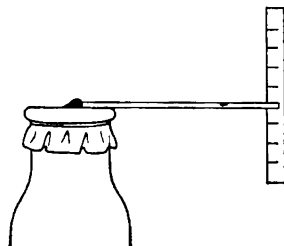


FIG. 20

Experiment 9.28. In both cases air flows from the higher to the lower pressure.

ANSWERS TO QUESTIONS

1. 'Potty putty' bounces like rubber and yet is brittle when hammered hard. It flows very slowly—a lump the size of a tennis ball would flow into a puddle in a matter of an hour or so.

2. Diamond is the hardest known substance, natural or man-made, and is used to cut and abrade a variety of other materials, e.g. tungsten carbide (the second hardest material) used for drills, germanium and silicon for the electronics industry.

Diamond used for *cutting*:

Diamonds, other gems.

Rock drilling—before explosives are inserted.

Tunnelling—as in the St. Gotthard Tunnel.

Sinking oil wells.

Dentists' drills.

Diamond powder is impregnated into Bakelite, ceramics or metals for use in *grinding and sawing*:

Concrete, stone, slate, glass for lenses, gems, ceramics, glass-reinforced plastics, copper printing rolls.

Diamond powders are used intensively for *polishing* whenever a high quality finish is required:

Lens surfaces, gems, rounding edges of sheets of glass for car windows, plate glass doors, etc., gold watch cases.

Styluses—gramophone needle.

Chalk is hardly ever used in 'blackboard chalk' now. Because it crumbles so readily it is used in distributing fertilizers.

3. Diamond is very hard because its molecules are stuck firmly to one another in all directions.

4. (1) 14 in.

(2) 18 in.

(3) 20 in.

5. (1) $\frac{1}{2}$ lb.

(2) $2\frac{1}{2}$ lb.

(3) 3 lb.

6. (1) 6 in.

(2) 12 in.

7. It is the large *pressure* exerted on the hand by the wire which is the cause of the pain. The weight of the case is spread over a larger area when the handle is used, so that the pressure on the hand is decreased.

8. When stiletto-heeled shoes are worn, there are times when most of the weight of the person is pressing on the very small area of the heel. The pressure on the floor at that point is therefore very high and indentations are likely to appear. When flat heels are worn, the weight of the person is always distributed over areas at least ten times as great. (Stiletto heels are often of metal.)

9. A 'sharp' knife is one which has a fine edge—so that when a certain force is applied this pushes over a very fine strip of area so that the pressure is great and the knife is able to cut easily.

10. When lying in bed one's weight is distributed over the large area of contact between the body and the bed so that the pressure exerted by the bed on the body is small.

The area of wire on which one sits is obviously much smaller so that the wire exerts a much larger pressure.

(Such topics as stability or softness might well be presented as valid solutions to this problem.)

11. 5 tonf/in².

12. 70 lbf/in².

13. 300 gf.

14. 847 gf.

15. $\frac{1}{20}$ cm².

16. When the gas tap is turned on the gas will force water down the glass tube until the head of water in the surrounding measuring cylinder is sufficient to prevent further flow. The height of the head should be read, giving the pressure of the gas supply directly in 'inches of water', or 'centimetres of water'.

17. Mercury is suitable. Its density is 13.6 g/cm³.

18. 21 ft of water at least.

19. Lead and iron float on mercury. Gold doesn't.

20. When you lie on a hard floor, all of your weight presses on to the floor and the floor pushes back just as much—so you feel a big force acting on the areas in contact with the floor.

When lying in the bath, your body is partially supported by the upthrust of the water acting over a much bigger area. Therefore your body does not push down as hard on the bath so the bath doesn't push back as much as the hard floor. You feel a comparatively small force on the areas in contact with the bath and are therefore more comfortable.

21. Salt water is denser and therefore more buoyant than fresh water. So when a ship carrying a certain load travels from salt water to fresh water it sinks further into the fresh water—so that the loading line must then be higher on the ship's side.

22. The density of warm water is less than that of cold water and so the ship sinks farther into warm water.

23. Since the molecules are confined in a smaller space they will hit the cylinder walls more often.

24. The gas pressure would increase.

25. You could connect a Bourdon gauge to a bicycle pump and watch how the pressure reading changed as the plunger is inserted. (An adaptor as used to blow up a football would be a useful connector.) Nuffield Boyle's Law Apparatus, (N.109).

26. If you breathe onto a piece of glass or other cold surface you can see the water droplets formed when the water vapour in your breath has condensed.

On very cold days you can see water droplets forming a mist as the moisture in your breath condenses on the cold air.

27. It is difficult to separate the hemispheres because there is very little air inside them pushing them apart but air at atmospheric pressure pushes them together.

28. If the air in the bell jar is pumped out, the pressure of the air above the cork will be less than the pressure of the air in the bottle and the cork will pop out of the bottle.

29. If the tumbler is inverted carefully, the air pressure pushing

up on the card is sufficient to support the water in the tumbler and the card remains 'stuck'.

30. The force of the air pushing up on the bottom of the column of liquid supports the weight of liquid and any downward force due to pressure of trapped air.

31. When air is drawn out of the straw the pressure of the air above the milk in the straw is reduced. Atmospheric pressure transmitted through the liquid pushes the milk up into the straw.

32. A motor extracts air from the cleaner causing low pressure. Atmospheric pressure then pushes air (and dust) into this low pressure region and dust is deposited, clean air being forced out at the back.

33. Experiment 9.21.

34. A barograph is an aneroid barometer which records the variations of atmospheric pressure (Fig. 21).

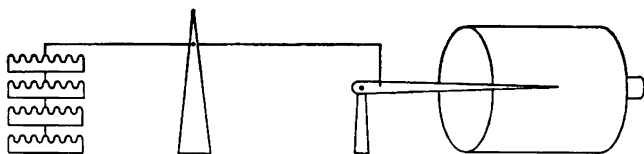


FIG. 21

Rhymes such as those referred to in the text are:

A red sky at night—a shepherd's delight.
But a red sky at morning's a shepherd's warning.

Mist in the hollow,
A good day will follow.

Rain before seven
Dry before eleven.

If the ash before the oak
Then we're going to have a soak.
If the oak before the ash
Then we're going to have a splash.

35. A depression is a region of low pressure. It therefore contains low density air, i.e. moisture-laden air. When air streams of higher pressure arrive (i.e. denser and therefore drier air) the moist (less dense) air is forced upwards.

36. Barometric pressure is about 75 cm of mercury. Mercury is 13.6 times denser than water and therefore the height of water which the atmosphere could support is about 1 000 cm.

37. It depends on how hard you push!

38. When the piston is pushed down—

(a) Valve A is pushed closed by the high pressure water in chamber X and valve B is forced open by this high pressure water.

(b) Water in chamber X is under high pressure.

(c) Water flows from chamber X out through the valve B into chamber Y and out of the pipe.

39. The outlet pipe protrudes into chamber Y so that air is trapped above the exit in Y. When this air is compressed by rising water the air exerts a larger pressure and forces the water out of the outlet. This helps to maintain a steady flow of water while the piston is being drawn up.

10 Heating Matter (pp. 80–90)

Introduction

Throughout these experiments we hope the pupils will think about what is happening to the materials they are handling.

It is not essential to do every experiment in this chapter, but if the apparatus is available, it would be a pity if pupils did not have an opportunity to see it.

Later in the course we shall be glad to discuss as many different energy changes as the pupils can recall.

Experimental Work

Experiment 10.1. The heated wire expands and sags. It contracts on cooling when the current is switched off.

Experiment 10.2. This is probably more suitable as an optional project for any quick pupil with special interest in this work. He will need several long tubes perhaps heated by steam passing through them, with a sensitive measuring instrument perhaps a micrometer screw gauge.

Demonstration 10.3. When the metal ball is heated it expands and will not go through the hole.

The ring is heated by contact with the ball, it expands and the hole becomes large enough for the ball to slip through.

Demonstration 10.4. The strain exerted on the pin as the hot metal bar cools and contracts is sufficient to fracture the pin.

Experiment 10.5. The expansion of copper is greater than that of iron.

Experiment 10.6. (a) When the flask is immersed it expands and its volume increases so the level of the meths falls. When the meths eventually heats up and expands more than the glass the level rises.

Keep away from open flame.

(b) As the expansion of the plastic is greater than that of the water, the level in the tube never rises. This is not evidence that water contracts when heated!

Experiment 10.7. For teacher's reference :

Coefficient of cubical expansion of methylated spirit	$= 120 \times 10^{-5} \text{deg C}$
Coefficient of cubical expansion of paraffin	$= 95 \times 10^{-5} \text{deg C}$
Coefficient of cubical expansion of water	$= 21 \times 10^{-5} \text{deg C}$
Coefficient of cubical expansion of mercury	$= 18 \times 10^{-5} \text{deg C}$

Demonstration 10.8. The volume is least at 4°C when the density of water is greatest.

Experiment 10.9. The temperature of a salt and ice mixture is less than 0°C .

The aspirin bottle breaks as water expands on freezing. Make sure no air is trapped in the neck of the bottle.

Experiment 10.10. Meths can easily ignite if heated over an open flame.

Boiling point of brine (saturated) $= 103^{\circ} \text{C}$

Boiling point of methylated spirit $= 64^{\circ} \text{C}$

Experiment 10.11. The boiling point of brine is greater than that of pure water.

Demonstration 10.12. It is possible to show that water will boil right down to the temperature at which it freezes. Put a beaker of water under a bell jar with another beaker containing some concentrated sulphuric acid to absorb water vapour and so reduce vapour pressure. Evacuate, and at a certain pressure the water will boil—and continue to do so until, when the pressure is low enough, it suddenly freezes over.

Demonstration 10.14. The ether evaporates rapidly and takes heat from the liquid ether and the water in the test tube. The water eventually freezes.

Experiment 10.15. This experiment should encourage an informal discussion of thermal capacity.

Experiment 10.16. This should be a demonstration as pupils might be tempted to heat the mercury for longer than 15 seconds and mercury vapour is poisonous. Also, large quantities of mercury would be required for pupil experiments.

An informal discussion on the idea of specific heats should be encouraged.

Experiments and Demonstrations 10.17. (1) When the temperature

of the air increases the liquid level will fall. Variation of atmospheric pressure will affect the readings to some extent.

(4) The meter is an ohmmeter.

(5) Copper and constantin are suitable metals for the thermocouple.

(7) These are known as 'Seger cones'.

Demonstration 10.19. It is difficult to ensure that the lid is airtight and yet not rammed on too hard. However, it is worthwhile because it illustrates in an impressive way the important fact that when air is heated at constant volume the pressure increases.

Demonstration 10.20. Equal volumes of gas at the same pressure expand by equal amounts when heated through the same temperature range.

Experiment 10.21. As the air is heated its pressure and volume increase and the balloon is partially blown up.

Experiment 10.22. As hot air is less dense than cold air the upthrust on the balloon is greater than its weight.

A gas-filled balloon is only partially filled when it leaves the ground to allow for expansion of the balloon as it ascends into less dense air. The density of the gas is less than the density of the air.

This is not suitable for a class experiment, but could be set for homework.

Demonstration 10.23. The cork-and-disc arrangement can be replaced by a loosely-fitting cork (Fig. 22).

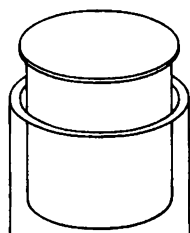


FIG. 22

Experiment 10.24. For a convincing demonstration, place the junction of a sensitive thermocouple in the end of the bicycle pump. A sensitive galvanometer (Scalamp or Galvo-amplifier, J.J. instruments) will record the change in temperature.

Demonstration 10.25. (a) The mercury ensures good thermal contact between the bulb and the cylinder.

- (b) The temperature increases as the air is compressed.
 (c) As the air pressure inside the container is rapidly reduced the temperature falls.

ANSWERS TO QUESTIONS

1. Pitch is poured between the small sections of a concrete motorway so that on hot days the pitch will melt and allow for the expansion of the concrete.

2. To allow for the expansion of the pipes without undue stress when they are heated.

3. Special joints for hot-water pipes. Split piston-rings on pistons of internal combustion engines.

Roller-bearings on bridges, e.g. Forth Bridge.

N.B.—Railway lines are often welded nowadays.

4. The steel rim may be expanded by heating electrically and/or the steel wheel shrunk by immersing it in solid carbon dioxide.

5. We refer to a foot of the metal because when heated, the increase in length is directly proportional to the initial length.

6. See Fig. 23.

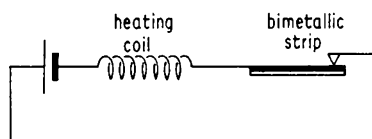


FIG. 23

7. Ice, ice lollies, ice cream, butter, cooking fat, solder, lead, candle wax.

8. Mercury.

9. Because the metal expands as it solidifies, the outlines of the letters become sharp and the print is clear.

10. Cubical coefficient of expansion of mercury = $18 \times 10^{-5} \text{ deg C}$

Cubical coefficient of expansion of water = $21 \times 10^{-5} \text{ deg C}$

11. Cubical coefficient of expansion of alcohol = $108 \times 10^{-5} \text{ deg C}$

12. Vapour.

13. Boiling point of water = 100° C (at atmospheric pressure).

Boiling point of meths = 64° C .

i.e. Meths boils at the lower temperature.

14. The boiling point of water on a mountain is below 100° C .

e.g. On Mont Blanc's peak (16,000 ft) it is about 83° C and at the top of Mount Everest (29,000 ft) it is about 70° C .

15. It is, in fact, possible to cook an egg in water which is maintained at a temperature below 100° C .

16. A food storage cupboard—'Osokool'.

Milk jug cooled by moist muslin—or a modern version, foam-rubber milk-bottle jackets.

Eau-de-Cologne dabbed on the forehead.

The wet-and-dry bulb thermometer.

Very volatile liquids such as ethyl chloride are used in medicine to freeze small parts of the body so that no pain is felt during operations.

Sweat from the body.

In some refrigerators cooling is obtained when either liquid ammonia or liquid carbon dioxide evaporates.

17. The temperature rose steadily to about 100°C , and then remained constant.

18. The bus, although under certain circumstances it could be the motor-cycle.

19. The bike.

20. Mercury, alcohol.

	<i>Boiling point</i>	<i>Freezing point</i>
Mercury	357°C	-39°C
Alcohol	78°C	-114°C

22. The freezing point of the mixture would be affected by impurities, perhaps unsuspected. Blood temperature is affected by muscular activity, surrounding temperature, age, general health, etc. It varies for different people, but this variation is less than 3%.

23. See Fig. 24.

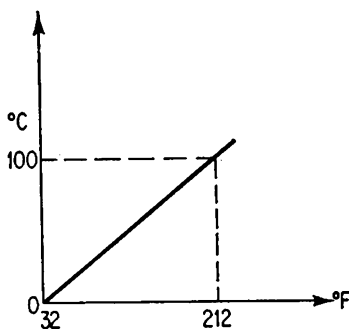


FIG. 24

24. (a) 40°F .

(b) 140°F .

(c) 167°F .

25. (a) 5°C .

(b) 20°C .

(c) 37°C .

26. It is normal human body temperature.

II Push-push. Pull-pull (pp. 91-102)

Introduction

The concluding three chapters of the text form a concise introduction to many aspects of physical mechanics, appropriate to the level of ability of the pupils at this stage.

We have already dealt with the properties of matter in the large and with the micro-properties of matter. Now we proceed to consider the forces of interaction between matter.

From the pupils' point of view, we should bear in mind that they have been familiar with forces and motion all of their lives. What we seek to do now is to systematise this knowledge. This synthesis was first accomplished by Galileo and Newton, and what we require are the ideas and concepts of Newton's laws of motion without any formal statement of them. We also need to give some thought to the various types of forces encountered. From the physicists' point of view, there are only four forces in nature, gravitational, electrical and the strong and weak nuclear forces. This is too sweeping a generalisation at this stage for our pupils but we need some appreciation of the nature and effects of the intermolecular forces between bodies in contact and of the gravitational, electric and magnetic forces which act at appreciable distances.

Briefly the work in mechanics is divided as follows:

Chapter 11. Dynamical aspects of force and motion.

Chapter 12. Forces on bodies at rest—statics.

Chapter 13. Work, machines and energy.

Forces and energy provide us with the two main approaches to the study of mechanics.

At this stage it would be advisable to refer to *Physics is Fun* Book Three to ensure that the foundations may be laid here, in the first year, for the more quantitative study of mechanics in the third year.

It may be of assistance to summarise just what we need to accomplish in this introduction (Chapter 11) to the dynamical aspects of forces and motion. The work falls naturally into two headings:

- (1) A survey of force and types of forces.
- (2) The laws of force and motion.

A survey of force and types of forces.

(i) Ideas of force

—introduced by muscular effort; push, pull, twist and squeeze.

(ii) Effects of force—forces produce:

(a) Motion

—when we kick a ball or fire a rocket into space.

(b) Change of motion

—friction slows things down so we require ball-bearings in the wheels of bicycles and mechanics trolleys.

—gravity produces the projectile path of a ball in flight and the orbital motion of planets and satellites.

(c) Change of shape

—distortion of solids, as in stretching our elastic band or when a rubber ball bounces on hard ground.

—a means of measuring forces or comparing them by the stretch of a spring or bending of a cantilever.

(iii) Types of force:

(a) Contact forces

—intermolecular forces in solids, as when we bounce a ball or pull a piece of string till it breaks.

—intermolecular forces between the surfaces of solids in static and dynamic friction.

—intermolecular forces in fluids, as in air friction or the viscous effects in liquids.

(b) Action-at-a-distance forces

—gravity on a projectile or jet of water.

—magnetic forces between magnets mounted on trucks on model rails.

—electrical forces between charged soap bubbles and a Van de Graaff generator.

The laws of force and motion.

(i) *Motion under the action of no forces—Galileo and Newton I—the law of inertia.*

—that uniform motion in a straight line is the 'natural' thing, only when unbalanced forces act is there a change in the motion.

—proceed from toy cars or trolleys to balloon pucks and linear air track.

—rest is only relative to the frame of reference.

—reduce frictional forces to attain ideal state of uniform motion by oiling and greasing of bicycles and cars, use ball-bearing wheels.

—tendency to stay at rest or keep on moving at uniform speed in a straight line—*inertia*—by comparing kicking a ball and a brick, considering acceleration and deceleration in buses and lifts, by throwing up a ball in a moving railway carriage.

(ii) *Forces produce accelerated motion—Newton II— $F=ma$.*

—forces overcome the inertia of bodies—pull brick with spring balance.

- forces produce accelerations—constant stretch of elastic on trolley.
 - forces produce changes in momentum—collisions of marbles.
 - acceleration produced in a mass provides the measure of a force and the absolute meaning of force independent of gravity.
 - (iii) *Forces occur in pairs—Newton III—action and reaction.*
 - difficulty of isolating a single force.
 - action and reaction pairs of forces—show trolley 'twins', magnetic trucks on rails, consider firing guns and rockets.
 - reaction to a force by placing weight on Salter balance.
 - forces balance in pairs to give equilibrium as in a tug-of-war.
- This now leads to the study of forces in equilibrium—statics (Chapter 12).

The following experiments are perhaps the most important in this chapter.

(a) *Introduction to measurement of forces.*

Experiment 11.1 Elastic materials and springs.

Experiment 11.17. Calibration of a spring balance (also Experiment of 9.2 if not done).

Experiment 11.26. Measurement of static forces in series and parallel.

(b) *Survey of the effects of forces and the types of forces.*

Experiment 11.2. Uniform motion.

Experiment 11.4. The effect of friction.

Experiment 11.6. 11.8. Fluid friction.

Experiment 11.10. 11.11. Free fall under gravitational forces.

Experiment 11.14. 11.15. Projectile motion under gravity.

Experiment 11.18. 11.19. 11.20. 11.21. Electric and magnetic forces at work.

(c) *Introduction to the laws of force and motion.*

Experiment 11.31. 11.33. 11.34. Illustrations of idea of inertia.

Experiment 11.32. Constant force produces acceleration.

Experiment 11.24. 11.30. Action and reaction.

This is an important part of the work and at least four or possibly six double periods could be devoted to it.

Experimental Work

Experiment 11.1. Aim here to show (i) the properties of elastic materials through the action of forces and suggest some molecular explanation in terms of intermolecular forces and (ii) practical use suggested by these properties for measurement of the forces. The importance of elastic materials depends on the fact that after deformation they return to their natural length or size if the elastic

limit is not exceeded. Springs can be stretched beyond their elastic limit to show this.

For a detailed discussion see Rogers, p. 79.

Nuffield elastic materials kit (N.2) could be used, and also balls supplied by Dunlop Rubber Co. including one of low hysteresis rubber.

Experiment 11.2. Show that if we start with a block of wood sliding on the bench and reduce friction, by lubrication, by rollers, by adding wheels (mechanics trolley), by riding on air (dry ice pucks, hovercraft and linear air track) we attain in the limit, uniform motion at constant speed in a straight line under the action of no net force. The origins of this idea might be given and Galileo's argument as theoretical background.

Refer to *P.I.F.*, Book Three, p. 48, or Rogers, p. 278 and *P.S.S.C.* Text, p. 309.

Experiment 11.3. By blowing on a table tennis ball its speed can be increased or decreased, and its direction can be changed. Ask pupils if they can move a brick by blowing through a milk straw. It can be done if brick is suspended by strings and we blow in resonance with natural period of swing. Resonance is a fundamental concept at a later stage.

Experiment 11.4. Again relate the molecular picture to the physical facts; that friction depends on the normal reaction and nature of the surfaces but not for instance the area of contact. The limiting nature of the force of friction and the smaller force of dynamic friction once motion ensues, can be shown with shirring elastic or simply elastic bands, noting the extension as a measure of the force.

For the molecular picture see Rogers, pp. 343-4.

With spring balances bricks wrapped in brown paper to avoid scratching the bench are more suitable than wood blocks.

The Nuffield friction kit (N.55) is useful for elementary friction experiments.

Experiment 11.5. Cohesion and also adhesion provides more evidence for the molecular nature of the forces. Considerable forces of cohesion are possible with flat surfaces of lead hammered together. Slip-gauges used in metrology labs are 'wrung' together.

Experiment 11.6. Our theoretical picture so far should suggest similar forces will be found in liquids, i.e. frictional or viscous forces. Idea of terminal velocity could be mentioned as it is important for Millikan's experiment later in the course.

Experiments 11.7–11.9. The search for frictional forces extended to gases. Terminal velocity may be mentioned again in connection with sky diving. The problem of re-entry to the atmosphere of space capsules is also of interest here. The heat produced as a result of friction with the air requires the design of special heat shields made of new materials such as 'Pyrosil'. The space vehicle is of course slowed down by this force of friction in the atmosphere.

Experiments 11.10–11.11. In Experiment 11.2 friction makes it difficult to see that under the action of no forces uniform motion at constant speed will result. Here, when we study gravitational forces, friction again complicates matters. If we can get rid of friction—Newton's 'guinea and feather' experiment—we get uniformly accelerated motion of different masses under the action of the force. We can then vary the masses and compare results to find that the gravitational force increases in proportion to the mass of the body in such a way that the same acceleration is produced. Again Galileo's hypothetical argument for linking two equal masses to double the mass provides good theory.

For discussion see Rogers, Ch. I. For photographs see *P.I.F.*, Book Three, p. 40. Iron weights, released by an electromagnet, can be compared for time of fall by listening to impact with the ground. Special tubes for Newton's experiment—Nuffield (N.110) and Edwards. Note danger of implosion with a thin-walled tube.

Experiment 11.14. Projectile motion under gravity is of considerable importance. Newton's 'thought experiment' of firing a cannon from a very high mountain can be related to motion of Earth satellites.

Refer to Rogers, p. 38, and *P.I.F.*, Book Three, p. 55; photographs, pp. 53, 57.

A better method is shown in Fig. 25. A fine glass nozzle is fed from a constant head water supply via rubber tubing. The nozzle is attached by thread to an Advance vibration generator. This may be illuminated with a xenon strobe lamp or a compact light source (N.21) with the light shining through a rotating strobe disc.

Experiment 11.17. Note that the extension of a spring provides a practical method of measuring forces at any particular location where the calibration is carried out. If this is done on the Earth's surface, it will not apply in space or on the Moon. This is why we need our absolute measurement of force based on Newton's second law. The unit of weight (force) is the Newton. Refer to Hooke's law, *P.I.F.*, Book One, Ch. 9, Experiment 9.2 if not already done. Elastic bands may be calibrated for measuring forces but do not give a linear scale.

Experiment 11.18–11.23. We must extend our survey of forces to cover electric and magnetic forces which are of fundamental importance. Electrical forces are fundamental, giving rise to magnetic forces and intermolecular forces. Comparatively much stronger (10^{39} times) than gravitational forces they show repulsion as well as attraction.

Nuffield pucks kit (N.95) and electrostatic kits (N.5) are useful. Eclipse bar magnets are to be recommended for magnet experiments. Note that glass sheet (Experiment 11.22) is not a good insulator—use Perspex sheet.

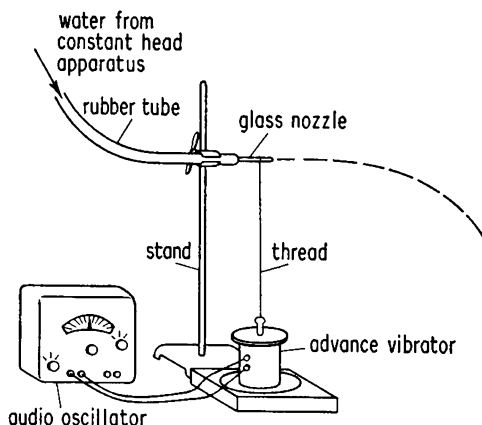


FIG. 25

Experiment 11.24–11.25. Discussion of Newton's third law is difficult and should not be laboured here.

We are concerned with the mutual forces of interaction between two bodies. What we seek to establish is that any force originating from the boy and acting on the girl must necessarily be accompanied by a force originating from the girl acting on the boy; we cannot get a *single* force in isolation. These action and reaction forces are equal in magnitude but opposite in direction and act on *different* bodies.

For a good discussion see Rogers, pp. 129 and 146–9, also *P.I.F.*, Book Three, p. 88. Many variations of this experiment are possible with pupils standing on roller skates or mechanics trolleys.

Nuffield water rocket (N.167) is very useful here.

Experiment 11.26. Some simple statical arrangements of forces in series and parallel, such as indicated in the text, allow pupils to come to grips with the practical problems of isolating and measuring forces, and give some ideas of forces.

We must distinguish clearly the forces and on what they act (Fig. 26).

Consider the weight. The forces acting on it are F_G the forces of gravity down and F_{BW} the force exerted by the spring balance on the weight. Since the weight is at rest the resultant force is zero ($a=0$ so $F=0$ by Newton II) so these forces are equal and opposite $F_G = -F_{BW}$. Similarly for the spring balance the force of the support on the balance F_{SB} is equal and opposite to the force of the weight on the balance F_{WB} and this is the force indicated by the reading on the spring balance. (By Newton III $F_{BW} = -F_{WB}$ these forming an action-reaction pair, so that $F_{WB} = -F_{BW} = F_G$ the weight of the 'weight'.)

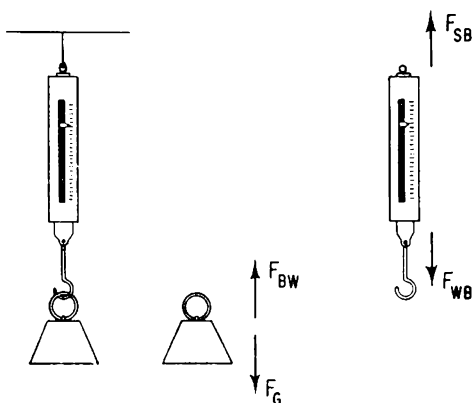


FIG. 26

For pupils at this stage a simple explanation, such that in series the balances transmit the force one to another; in parallel they share the force, will suffice. However good pupils may not be satisfied with this. Opportunity might also be taken to support a weight with two spring balances held at an angle to one another and discuss the limiting positions in this case.

Experiment 11.29. (a) Both.

(b) The momentum with which you leave the floor is equal and opposite to the momentum you impart to the Earth. When you jump down again the Earth 'comes up to meet you' very slightly!

(c) Both.

The change of momentum (=impulse) is much greater in the case of the stone.

(d) Yes.

On roller skates you cannot exert such a strong force on the wall.

Experiments 11.31. 11.33. 11.34. Good illustrations are necessary to introduce the concept of inertia. We must relate this to our ideas of motion already encountered (Experiment 11.2) and the ideas of Newton's first law—the law of inertia. For motion to result we must overcome the tendency of bodies to stay at rest (or to change their motion)—their inertia; and note that more massive bodies have a greater tendency to oppose change of their motion i.e. greater inertial mass.

Experiment 11.32. A steady force appears to produce a steady motion. This is the paradox. Again friction is the culprit. If we supply a force to counterbalance frictional forces we have zero resultant force and motion at uniform speed results. If we have a net force we get acceleration and if the force is constant, then uniformly accelerated motion results.

This gives the essential ideas of Newton's second law.

Refer to *P.S.S.C. Text*, Ch. 20, and *Rogers*, Ch. 7.

Experiment 11.33. With a steady pull the tension in A will be 4 lbf greater than in B because of the weight. A will therefore break before B.

If the thread B is pulled sharply the inertia of the 'weight' prevents the force from being transmitted to A before B breaks.

Experiment 11.34. Because of the inertia of the coin it tends to remain where it is when the card is knocked from under it. The force of friction is not great enough to move the coin with the card if it is sharply struck.

ANSWERS TO QUESTIONS

2. By the fact that it produces or alters motion, or causes deformation of some kind.

3. Elastic material.

4. Yes.

5. Stretch of elastic band, stretch or compression of a spring.

Also bending of a beam or torsion of a wire.

6. Spring or lever balance.

7. Change speed, change direction, deformation.

8. Frictional force between sand and boat greater than that of water.

9. To reduce friction between the metal surfaces.

10. To reduce air resistance.

11. Friction between the air and the outer skin of the capsule results in the production of heat at such high re-entry speeds.

12. Because it impedes progress.
13. Walk, leap or run, swim.
14. Motion or deformation.
15. Acetate is a much better insulator and so the electrons are more tightly bound.
16. Negative.
17. Repulsion by another charged polythene rod.
18. They attract one another.
19. They repel.
20. (a) Like charges repel.
(b) Unlike charges attract.
21. Each exerts a force on the other, the forces being equal and opposite.
22. Yes.

The force which has a disastrous effect on the window will probably not damage the ball.

23. By throwing his school bag in the opposite direction.

24. Because gas is ejected backwards thrusting the rocket forwards.

This is an interesting application of Newton's third law and the principle of conservation of momentum. The rocket exerts the active force on the hot gas which in turn exerts the reaction force on the rocket.

From the momentum point of view, if no external forces act, the total vector momentum of rocket and gas must remain zero, the momentum of the ejected gas backwards is equal to the momentum of the rocket forwards. The analogy with a machine-gun firing a stream of bullets may be useful here *P.S.S.C. Text. Chs. 23-5*.

25. Because it has a greater mass and weight.

Weight does enter here because the weight will determine the normal reaction of the supporting surface and so the force of friction to be overcome.

26. No.

Because of the greater inertial mass to be overcome to get it moving.

27. Air friction.

28. The car moves faster.

Provided the driving force is greater than any frictional force.

29. To increase speed in any interval of time.

30. To make it accelerate.

31. Will use more petrol if it accelerates all the time.

32. Heavy bodies are accelerated less for a given force.

Acceleration is inversely proportional to the mass for a given force.

This is Newton II— $\text{mass} \times \text{acceleration} = \text{constant}$.

33. The heavy body.

For a given distance the force required to bring the body to rest

will be a measure of its kinetic energy which is proportional to the mass.

34. Push two trolleys, one empty and one loaded, at the same speed and allow each to run into a brick or heavy stool placed on its side. For this experiment the spring plungers should be left sticking out and the amount they are pushed in will give a measure of the force required to stop each trolley. A simple scale may be marked on the plungers to assist in this. See also Rogers, p. 380, and *S.E.D. Memorandum No. 9* (Revised), pp. 1-3.

35. To give it greater momentum.

36. You are 'flung forwards', i.e. tend to keep on moving at a steady speed on account of your inertia.

37. To prevent people moving on when the car stops suddenly.

38. Yes. In overcoming the inertia of the car.

The impulse produced in the change of momentum would produce damage.

39. Yes. Again to overcome inertia. If the body had mass a force would be required to produce acceleration.

12 Turn. Twist. Topple (pp. 103–110)

Introduction

In this chapter we study some of the general principles of statics. We have already established that if the acceleration of a body is zero the resultant or unbalanced force on the body is also zero (Newton II); and that for a body in equilibrium the upward forces equal the downward forces i.e. the vector sum of the forces is zero (Experiment 11.26). Here we introduce the second general condition for equilibrium, that the sum of the moments of the forces must also be zero; and examine some of the consequences of the principle of moments.

From the pupils' point of view we introduce the idea of the turning effect of a force and establish the empirical 'law of the lever'. We continue with the twisting action of a couple and then proceed to consideration of centres of gravity and stability of bodies.

Probably two double period lessons would cover this work adequately; one on moments and the principle of moments, another on centres of gravity and stability.

Important experiments are Experiment 12.1 together with Experiment 12.5; and Experiment 12.3 followed by Experiment 12.8.

Experimental Work

Experiment 12.1. Pupils should be set the empirical task of finding the relationship between the number of units of force and the number of units of distance, on either side of the pivot, necessary to produce balance. Some may suggest 'addition' as the relationship and this will be true in particular cases. However they can be left to find that 'multiplication' of these two quantities will alone give balance in all cases. This can be taken as the 'law of the lever'.

If slotted weights and hangers are used, each can be taken as representing one unit of force, and the metre stick can be marked off from the centre in units of distance of say 10 cm. The numerical relationships will then be simpler to handle and the results more obvious. A diagram, or sketch of each arrangement tried, can be drawn and the results tabulated.

Corresponding to the first condition for equilibrium already encountered, i.e. that the upward forces equal the downward forces, pupils should be able to suggest the reading of a spring balance, if this is used to support the metre stick instead of the needle at the

pivot. The weight of the metre stick will enter here and can serve to introduce an extension of the experiment.

This will be more akin to the use of an actual lever if holes are drilled at other positions and the experiment left open-ended for pupils to select other pivots. Why the 'law' does not appear to hold in these cases will serve to introduce some consideration of the weight of the metre stick, and through which point acts the resultant of the weights of all the particles of the metre stick.

The Nuffield lever kit (N.5) is useful for introducing the law of the lever.

For further discussion see Rogers, pp. 374-5.

Experiment 12.3. The essential points are (1) the force of gravity acts on each particle of the cardboard sheet, these forces constitute a set of parallel vertical forces (Fig. 27 (i)).

The sum of all these forces is the weight of the lamina. This we can obtain from our first condition for equilibrium by hanging the card by a thread from a spring balance.

(2) To find where this resultant force acts, we use our second condition for equilibrium, that, if the card is at rest, the weight and the force in the suspension do not constitute a couple (Fig. 27 (ii) and (iii)) and so must be collinear.

This gives the line of action of the weight in one position, we require another to determine the centre of gravity uniquely (Fig. 27 (iv)).

We must note that the gravitational forces on each particle are not confined to lie in the lamina. Once we have found the centre of gravity we can check its position by supporting the lamina horizontally by a thread through this point, or balance it on a pencil point (Fig. 27 (v)).

Placing an additional mass at the edge of the lamina provides further application of these principles.

Experiments 12.5. 12.7. 12.8. Note that for a position of stable equilibrium a restoring force or turning moment will always act if the body is slightly displaced from the position of equilibrium. In terms of energy, which should be discussed later, in such a position the potential energy is a minimum and work must be done against gravity to displace the body.

Experiment 12.6. At its centre of gravity.

Initially the finger nearer the centre of gravity supports the greater load so that the force of friction is greater at that finger and the other slips along until it is slightly nearer the centre gravity and now supports the greater load.

Experiment 12.9. This is difficult because as you bend down your

centre of gravity moves outwards. When it lies beyond your toes, balance is not possible.

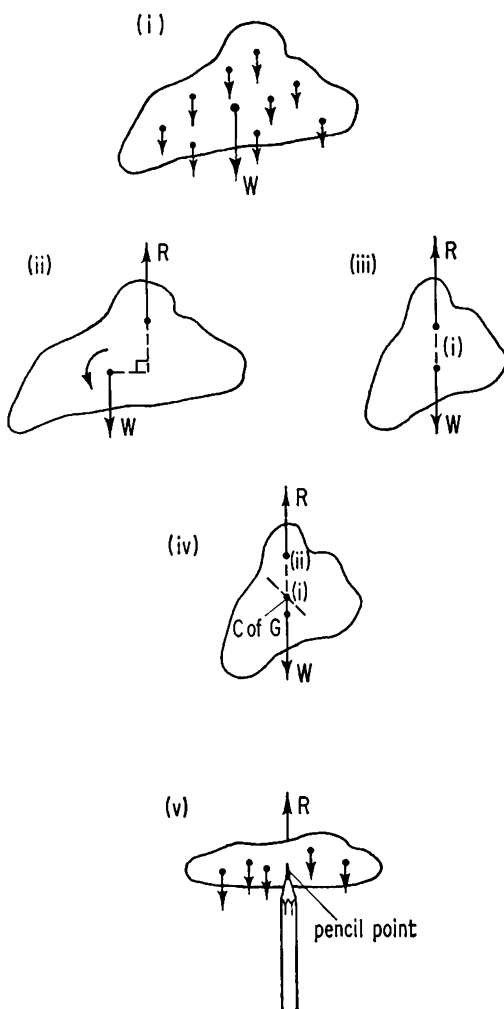


FIG. 27

ANSWERS TO QUESTIONS

1. Hold at C.
2. To get greater leverage.

The moment of the force would be greater because of the greater moment arm.

3. See Fig. 28.
4. A screwdriver.
5. Because it would give greater leverage.
6. No.
7. Turing effect depends on force and perpendicular distance from pivot.
8. Six feet from pivot.
9. Four feet from pivot.
10. Vertically.
11. Held horizontally there would be a turning moment to overcome.
12. At 'BB'.
13. The small moment arm of a wing nut gives little leverage compared with the long lever arm of a spanner on a hexagonal nut.
14. Close to the hammer head.
15. The point of balance of the ladder.

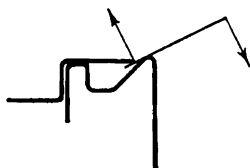


FIG. 28

16. Somewhere on the plumb line.
17. Below.
18. Yes.
If slightly displaced it will return to this position.
19. The cross bar.
20. To get the point of support directly above the centre of gravity so that the bicycle would be in stable equilibrium.
21. Suspend it from two different points, say the centre of the handlebars and the saddle pillar, and in each case Sellotape the thread of the plumb line to the frame. The centre of gravity would be at the position where the threads cross.
22. No.
This would be a position of neutral equilibrium.
23. Yes.
24. In a hollow in the road or in the gutter.
25. Stable equilibrium.
26. Unstable equilibrium since his centre of gravity is above point of support.
27. This enables him to vary the combined centre of gravity more precisely.
28. In each case the centre of gravity is directly below the point of support.

29. If the vertical through the centre of gravity falls outwith the point of contact of the base with the ground.

30. The greatest weight is in the engine and transmission system which is kept low. Superstructure is usually made of aluminium.

31. To keep centre of gravity low.

32. The one on the right.

33. See diagram (Fig. 29).

34. The 'low loader' on the right.

35. Because of greater stability.

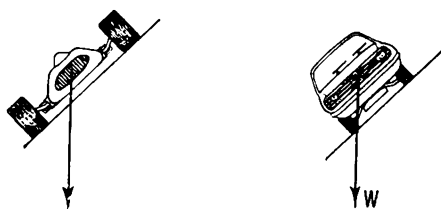


FIG. 29

13 Work—Work—Work (pp. 111–128)

Introduction

At this stage we introduce the fundamental concept of energy which provides one of the main themes of the course. Energy has many diverse forms, which will appear again and again throughout the course. However, we should avoid making energy appear as the excuse and explanation for everything. Our illustrations and examples should be chosen carefully to show the essential factors, force and distance, in this precise and measurable concept.¹ For mechanical energy this is relatively easy; to get over to other forms, such as heat and electrical energy, transformations of energy, in simple terms, are required; so that if a certain quantity of mechanical energy is transformed to heat, then we have a measurable quantity of heat energy also.

In the course of this work a most important conclusion must be reached, namely that the total amount of energy can never change—the law of conservation of energy, or more correctly, the law of conservation of mass energy.

Later on in the course we carry our ideas of energy back into the micro-world and study, for example, the energy concept in atomic particle collisions and in the thermal energy of colliding molecules in a gas.

Again it may be advisable to summarise what we wish to accomplish in our study of energy:

The concept of work.

- force, and distance moved in the direction of the force, determine work done.
- their product gives us the quantity ‘work’—a simple proportion argument shows this.
- a unit amount is necessary—illustrate with 1 lbf through 1 ft, etc.—also the joule (1 newton through 1 metre), (1N = 100 gf).
- illustrate by calculating work done by pupils climbing up stairs, or by raising a load by means of a model steam engine or electric motor.

The concept of power.

- rate at which work is done (or energy expended).
- illustrate by story of James Watt—Horsepower—the watt (J/s).

¹ Strictly we can only measure changes in the energy content of a body. There is no way of determining the total energy of a body. In fact we do not know what energy *is*. Certain rules give us a quantity which remains constant and this is what we describe axiomatically as energy.

- calculate the power of a pupil running up stairs or of model engine.

The concept of energy.

- energy acquired as a result of work being done.
- energy of a body measured, e.g. by how much work is done bringing it to rest.
(note that this involves a transformation of energy to some other form)
- forms of energy: mechanical, heat, electrical and internal molecular energy.
(require micro-picture of heat energy later)
- conservation of energy—no loss, only transformed—drill hard metal.
- draw diagrams showing chains of energy transformations.
- discuss energy transformation of a bouncing ball to internal energy of molecules.

Machines.

- machines are energy transformers.
- do not give more energy, usually less—idea of efficiency.
- may give greater force (M.A.) at expense of greater distance moved (V.R.).
- illustrate with lever, wheel and axle (possibly incline plane from energy considerations).

Forms of mechanical energy.

- potential energy as energy of position or stored energy.
(energy acquired in virtue of position above reference level in field of force.)
- kinetic energy as energy of motion—depends in some way on mass and velocity.
- illustrate by diagrams.
- discuss pendulum or spring showing interchange of P.E. and K.E.

Ideas of heat energy.

- heat energy from mechanical work—friction.
(conversion of mechanical energy to internal kinetic energy of molecules.)

- heat from electrical energy or vice versa—thermocouple.

For excellent discussions of energy see Rogers, Chs. 26, 28, 29.
P.S.S.C. Text, Chs. 24, 25.

Important experiments are as follows:

Experiment 13.2. Ideas and concepts of work and energy.

- together with work and power of pupils and model engines.

Experiments 13.3. 13.4. Simple machines

- also lever and possibly incline plane by energy method.

Experiment 13.14. Energy transformations.

Experiment 13.8. P.E. and K.E. interchange.

—also pendulum and helical spring in oscillation.

Experiment 13.21. Heat energy.

Experiment 13.22. Electrical energy.

About three double period lessons on energy, simple machines and energy transformations should cover this material.

Experimental Work

Experiment 13.1. Chemical—mechanical—sound—mechanical—electrical—mechanical—sound—mechanical.

Experiment 13.2. It probably will be necessary to emphasise that when we calculate work done the distance must be taken in the direction in which the force acts—this can be discussed in relation to a pupil climbing up stairs, the force supplied to overcome gravity is vertical so the vertical distance must be taken. Again we must note carefully whether the force acts against gravity in vertical motion or against friction in horizontal motion. Also the forces must be applied slowly otherwise acceleration is significant and so also the kinetic energy acquired.

(a) 10 lbf if the box is raised at constant speed. It moves in the direction of the force. You exert more than 10 lbf if the box is accelerated upwards.

In raising the box 1 ft you do work $10 \text{ lbf} \times 1 \text{ ft} = 10 \text{ ft lbf}$. If the box is released it will fall. It loses potential energy as it does so.

(b) More work is now done to raise the trolley and this is measured by its weight times the height raised.

(c) The force now depends on the friction in the wheels. It will be much less than 10 lbf and so the work done will be less.

The energy used is changed to heat and only a little to kinetic energy. It cannot be used to move the box again.

(d) We expect friction now to be greater so that the work done would be greater than in (c) but less than in (a).

Experiments 13.3, 13.4. It is instructive to introduce the pulley, and wheel and axle, by considering these as levers (see Rogers, p. 375).

A simple discussion only is required and formal results better left until third year.

M.A. is always less than V.R. Only in a perfect machine would they be equal. As there is always some friction present M.A. is less than V.R.

Experiment 13.7. Heat—chemical—mechanical—sound.

Demonstration 13.8. The interchange of kinetic energy of the moving disc with the elastic potential energy of the spring is an important example and should be discussed along with the oscillation of a

pendulum and of a loaded helical spring. The rotational energy stored in a flywheel has many practical applications and could be mentioned.

When the spring is wound the energy is stored as elastic potential energy in the spring. When the spring is slack and the wheel moving at maximum speed the energy is entirely kinetic.

Experiment 13.9. As the tin is rolled along, the hanging weight (which should be as heavy as possible) keeps the centre of the elastic from turning and the energy is stored in the twisting of the elastic. Some of this energy is transformed back to kinetic energy as the elastic tends to untwist again and provides the necessary force to roll the tin back some way.

Experiment 13.10. Many variations are possible with curtain rail in a loop or in the form of a roller-coaster track to show that in practice some energy is always 'lost'. A pendulum may be used for discussion of conservation also. See *P.I.F.*, Book Three, Project 8.9, p. 109.

(a) K.E. and finally heat.

(b) Because of friction some energy is always changed to heat and the cars will not reach the same level on the opposite side.

Experiment 13.11. The energy is now stored as gravitational P.E.

Experiment 13.12. P.E.—K.E.—P.E.

Experiment 13.13. The radiation heats the air in the flask which may expand sufficiently to raise the balloon.

Black surfaces are good absorbers as well as radiators of heat.

Experiment 13.14. The Malvern energy conversion kit (N.9) opens up many possibilities for the study of energy transformations.

Experiment 13.17. Broken glass can act as a lens which focusses the sun's rays.

Experiments 13.21, 13.22. These introduce heat energy and electrical energy which will be discussed in some detail later.

Experiment 13.21. (a) Glowing fragments of metal.

(b) If brakes are used often they become hot and less efficient.

Experiment 13.22. A 3.5 V torch bulb will burn out with a bright flash across a 6 V accumulator.

Experiment 13.23. Chemical—sound, light, heat—chemical change.

ANSWERS TO QUESTIONS

1. The different forms of energy are:

gravitational energy, potential energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, mass energy.

These divisions are somewhat arbitrary, for example, chemical energy is partly the kinetic energy of electrons in the atom and partly the electrical energy of interaction of the protons and electrons; radiant energy or light energy, is really electrical energy of electromagnetic waves.

2. Chemical, sound, electrical and mechanical.

Note the term "transducer" which is useful in this connection.

This is simply the name for an energy transformer, e.g. microphone or vibrator.

3. 4,000 ft lbf.

4. From the chemical energy transformed in the man's muscles.

5. (a) 8,000 ft lbf. (b) 12,000 ft lbf.

6. 100 ft lbf.

7. 5 ft.

8. Perpetual motion machines.

9. Some energy is always transformed to heat on account of friction.

10. 4 lbf.

11. 5.

12. 5.

13. Mechanical advantage.

14. Mechanical advantage becomes less.

15. M.A.

16. The weight of the bar would act against the effort.

17. 10 ft lbf.

18. 10 ft lbf.

19. Yes.

20. Stand the bicycle upside down, attach a load to rim of rear wheel and measure with a spring balance the effort required at the pedal to balance this. Measure or calculate distance moved in one revolution of the pedal and the corresponding distance moved by a point on the rim of the rear wheel.

21. No.

22. (a) 1. (b), (c) 2. (d) 2. (e) 3.

23. Heat, light and sound energy.

24. Because the force between them decreases very rapidly with distance.

25. (a) P.E. to K.E. (b) K.E. to P.E. to K.E.

26. Heat energy from the car heater.

Heat and light energy from the headlights.

Sound from the horn.

Movement from the starter motor.

27. Gas fire—heat, light and radiant energy.

Cooker—heat and radiant energy, and light.

Electric fire—heat and radiant energy and light.

Light bulb—heat and light energy.

Electric train—mechanical energy, heat and sound energy.

Vacuum cleaner—mechanical and sound energy.

Transistor radio—sound energy and heat.

Television set—sound, light energy and heat.

Clock, mechanical and sound energy.

Food and drink—chemical and heat energy.

Refrigerator—heat energy.

Car—mechanical, heat, light, sound energy.

Lamp—heat and light energy.

Fire—heat, light energy and radiant energy.

28. Electrical energy.

29. Transmission of electrical energy over long distances is possible.

30. Mechanical, light sound and electrical energy.

31. A thermocouple.

32. See *P.I.F.*, Book One, Fig. 127, No. 5.

BOOK TWO

Teachers' Introduction to Guide to Book Two

Aims

Before starting Book Two, a teacher should have clear in his mind what it is he and his pupils are attempting to do in these chapters. If he does not keep his main themes clear, he may tend to get bogged down in old favourites, such as the familiar experiments with convection phenomena, tuning forks, the various experiments illustrating straight line propagation of light, Ohm's Law and resistors in series and in parallel—and then find time woefully short!

Possible underlying themes could be:

For Chapters 1–3: the rate of flow depends on pressure, temperature or electric potential *gradients* and is affected by some other physical factors such as area of cross-section and the nature of the material—a theme which is further developed in later chapters.

For Chapters 4–8: the main ideas of:

- (i) energy transference by waves,
- (ii) the evidence, or distinguishing test (interference) for wave nature,
- (iii) reference to 'real life' illustrations or applications.

For Chapters 9–14: a development of the ideas of flow of electric charge, its control, measurement and its sources. The close relationship between magnetism and electricity is the final theme of this book.

Order

The teaching order given in the text is a possible one. Other possibilities exist. For example, in the work on waves, in the light of the chosen theme (ii) above and having explained the meaning and the significance of 'interference' by means of Experiment 4.18, a teacher may choose to delay Experiment 4.19 and 4.20 until the beginning of work with sound, 3 cm radiation and with light, and in each case ask pupils how they would propose to show that these could be considered as waves.

Another, perhaps more difficult, approach is to start with 'outside' illustrations familiar to pupils and attempt to show their common wave properties.

Wherever possible however, opportunity should be given for pupils to propose hypotheses, design experiments and test their findings *themselves*.

Time

Teachers should consider the time required for this work. A suggested distribution is 4–6 weeks on flow (Chs. 1–3), 10–12 weeks on waves (Chs. 4–8) and 14–16 weeks on electricity (Chs. 9–14). This will probably mean severe curtailment and selection of the work proposed in the text. It is a matter for each teacher to decide whether or not he could or should afford more time, and then as a consequence of this decision and his chosen main themes select the work he proposes to do.

Homework and Clubs

Homework could be written answers to the numbered questions asked in the text, but could also be little projects as described in some of the suggested experiments. Where whole portions of work have been omitted (considered as being not vital to the chosen themes, as in resonance and colour), these might be undertaken with interested children after school hours or in clubs.

I Fluid Flow (pp. 2-14)

Introduction

Distinction is first made, in Demonstration 1.1, between streamline and turbulent flow, essential to an understanding of drag.

Illustration of flow patterns round bodies of different shapes follows in Demonstrations 1.2 and 1.3, one of which could be omitted.

Experiment 1.4, which could be done at home, leads up to drag.

Fluid friction is investigated in Demonstration 1.5 and the effect of streamlining on drag in Demonstration 1.6.

Experiments 1.8-1.11 have the advantage of showing, with one piece of apparatus, how various factors affect the volume rate of flow of a liquid through a tube; if these experiments are used, 1.7 and 1.11 may be omitted. If, however, Experiments 1.8-1.11 are not used, Experiments 1.7 and 1.12 should be done, with the effect of bore and length of tube investigated with various versions of Experiment 1.7.

Demonstration 1.13 compares, very effectively, speeds of flow in tubes of different bore, and Bernoulli's principle follows, one or more of Demonstrations 1.14, 1.15 and 1.16 being suitable for its investigation.

Applications of this principle can be studied in Experiments 1.17-1.22, the first three of which are suitable for homework and the others being so easily carried out that none is worth omitting.

Experiments 1.23 and 1.24 on the effect of spin on the motion of a body are also suitable for trying at home.

The chapter is concluded with Experiments 1.25 and 1.26, illustrating the propellor effect and angle of attack respectively, both highly important factors in flight.

Experimental Work

Demonstration 1.1. It is essential for easy success to use a fairly long hypodermic needle (a No. 4 serum needle is about 5 cm long). A dropping funnel makes a convenient container for the permanganate solution which should be sufficiently concentrated to be easily seen; a white paper background helps.

Demonstration 1.2. As in Experiment 1.1, white paper behind the smoke makes the flow lines more easily seen.

Demonstration 1.3. A certain amount of difficulty may be experienced in providing a sufficiently broad stream of water, due to the reluctance of the water to wet the tray. While the use of a wetting agent may help, its effect has been found to be of short duration. Greatest success has been achieved by laying a sheet of white drawing paper on the tray and allowing the flow to take place over it.

As an alternative to the permanganate crystals and the Perspex strip, or the cheese-cloth, moving a hypodermic syringe along the top of the tray while releasing from it a series of drops of permanganate solution has been found to produce good stream lines.

Experiment 1.4. Greatest turbulence is produced when the blade is at 90° to the direction of motion. In this position there is greatest resistance to the motion of the blade. Oars are feathered (turned so that the blade is horizontal) so that, as they are taken back to the beginning of the next stroke, there is as little air resistance as possible.

Demonstration 1.5. Flow is fastest at the centre and slowest at the wall. Due to forces of attraction between the molecules of the wall material and the molecules of liquid nearest the wall, there is no resultant movement of the latter molecules in a direction parallel to the wall (ordinary molecular agitation will continue). The next layer of molecules is affected by forces between its molecules and those of the outer layer and is slowed down. In turn, molecules nearer the centre are affected. It will be as well to remember, in anticipation of the question from the brighter pupil, that molecules do not exist in layers and so the velocity changes continuously rather than in steps.

Demonstration 1.6. Metal discs should be added so that the total mass remains constant. Thus, when the body is displaced through a given angle with, e.g. the nose in position, the restoring force due to gravity is the same as it is when the metal disc replaces the nose.

Drag is least when both nose and tail sections are in place. It is increased when the nose section only is removed and is increased further when the tail section only is removed. When both nose and tail are removed drag is greatest.

The conclusion is that, at least at relatively low air speeds, the addition of a tail reduces air resistance more than does the addition of a nose.

Experiment 1.7. The greater the pressure difference between A and D, the greater the volume rate of flow. The use of the term 'volume rate of flow' in place of 'rate of flow' helps to avoid confusion between this quantity and speed of flow in, e.g. m/s.

Experiment 1.8. Repeating the experiment with a 500 g mass in place of the 200 g mass increases the pressure difference ($P_1 - P_2$) between the ends of the capillary tube and increases the volume rate of flow.

It is essential to make sure that the syringe and plunger are vertical, otherwise the time of descent may become extremely variable. Typical results using the suggested procedure are:

<i>Mass on plunger</i>	<i>Mean time of fall</i>
100 g	16.9 s
200 g	13.8 s
500 g	9.1 s

Each mean time of fall was found from six determinations, the times for which deviated by no more than 0.1 s from the mean. It is clear from this that, as the pressure at the inlet end of the capillary tube is increased, the volume rate of flow is increased. A fuller discussion follows, not intended for any but the brighter pupils who may wish to take the matter further.

The mass of the plunger was approximately 65 g. The cross-sectional area of the plunger was 6.3 cm^2 . Thus the pressures exerted by mass and plunger were about $26, \left[\frac{100 + 65}{6.3} \right], 42$ and 90 gf/cm^2 for the 100, 200 and 500 g masses respectively. The mean head of water from the level of the end of the capillary tube to the 40 cm^3 mark on the syringe, was 13 cm, giving 13 gf/cm^2 pressure. Therefore mean pressures during the fall of the three masses were approximately 39, 55 and 103 gf/cm^2 . As A.P. acts on the plunger and at the outlet end of the tube, these figures can be taken as values of $P_1 - P_2$. The products of $P_1 - P_2$ and mean time of fall are then approximately 659, 759 and 937 units respectively. While not good enough to allow the conclusion that time of flow is inversely proportional to $P_1 - P_2$ and so volume rate of flow is directly proportional to $P_1 - P_2$, it should be remembered that viscous forces in the water between the plunger and the syringe wall tend to slow down the fall and that these increase as the rate of fall increases. Thus the rate of fall of the plunger with a large mass on top is more seriously affected than the rate of fall with a small mass on top. Were this not the case the products quoted would be more nearly equal.

Experiment 1.9. To keep the pressure difference constant, use the same loading mass and the same range of fall of the plunger each time. As the area of cross-section of the glass tubing increases the volume rate of flow increases.

Experiment 1.10. The pressure difference can be kept constant as in Experiment 1.9. As the length of tube increases the volume rate of flow decreases.

Experiment 1.11. When hot water is used the volume rate of flow is increased. The viscosity of hot water is less than that of cold. With 'thicker' liquids (take care not to make them too thick!) the volume rate of flow is decreased.

Experiment 1.12. The ball bearings fall faster through the water. If the method is used to compare liquids the viscosities of which are not far apart, it is important to use ball bearings of the same size and to drop them down the middle of the jar used (one dropped near the wall will fall more slowly).

The use of a cardboard disc with a hole in the middle, placed on top of the jar, may help the less steady-handed pupil (or teacher!)

Demonstration 1.13. The water will flow faster in the narrower tube. Air bubbles are more easily induced to enter the wider tube if the outlet tube from the air reservoir is off centre.

Demonstration 1.14. The height of the water in B is less than that in A, as expected from the results of 1.7, but it is also less than that in C. Therefore the pressure in the narrower part of the tube, where the liquid is moving fastest, is less than that in the broader part of the tube.

Demonstration 1.15. The height of the flame from B is less than the heights of the flames from A and C. Therefore the gas pressure is lowest in the narrowest part of the tube, where the speed of flow is greatest.

Demonstration 1.16. The air speed is greatest where the gap between the plates is least. It is found that, at this point (middle manometer), the height of the water is greatest, i.e. the pressure of the air flowing between the plates is lowest.

Experiment 1.17. The paper is forced down between the books because the pressure below it has been reduced.

Experiment 1.18. Due to the fast flow of air, pressure above the roof is reduced below the normal A.P. Pressure under the roof equals A.P. Therefore the pressure below is greater than the pressure above; as the wind speed increases the pressure difference increases. Thus the roof is most likely to be blown off when the wind is strongest.

Experiment 1.19. The fast flow of air between reel and card reduces the pressure there. The greater pressure (A.P.) on the other side of the card holds it in place.

Experiment 1.20. The speed of flow of air from the vacuum cleaner is greatest in the middle of the stream (compare Experiment 1.5). If the ball moves to the right, say, the air on its left will be moving faster and so will be at a lower pressure. The ball will be forced back to its original position. (See *School Science Review*, Vol. 43, p. 173, and Vol. 45, p. 199, for discussion of associated points.)

The tube can be tilted and the ball held in position. In this case it begins to spin. If the air stream is tilted in the opposite direction, the direction of spin reverses too (see discussion in connection with Experiment 1.23).

Two balls can, with some difficulty, be supported for a short time. Whereas two identical balls are unsuitable since they tend to occupy the same position, two such as a table tennis ball and a 2 or 3 cm diameter polystyrene sphere can be used. Success has been achieved by holding them together in the air stream in loosely cupped hands and then gradually separating the hands.

A golf ball cannot normally be held up by the jet from a domestic vacuum cleaner, as the force which can be produced is not large enough to overcome the weight of the ball. To repeat this effect with a golf ball, a stronger jet of air is required, and the ball spins continuously.

If your vacuum cleaner does not produce a strong enough air flow for the experiments with the table tennis balls, a cork with a narrow glass tube placed in the outlet will improve matters.

Experiment 1.21. The fast flow of air in the narrow space between the funnel and the upper surface of the ball reduces the pressure above the ball. There is thus a resultant upward pressure and the ball is held up. A thistle funnel may be found to be better. If a table tennis ball is held at the end of the inverted funnel, blowing through the funnel (vacuum cleaner is not usually needed) leads to the ball being held in position.

Experiment 1.22. Pressure between the balls is reduced by the fast-flowing air and therefore A.P. is able to force the balls together.

Experiment 1.23. The spinning cylinder does not move in a straight line; its path curves upwards. The cylinder must be light and the effect may not be easy to produce using a cardboard cylinder such as a shuttlecock box. A cylinder made from a piece of drawing paper, rolled and Sellotaped, proves highly satisfactory.

Experiment 1.24. The ball does 'follow its face'.

Experiment 1.25. Each of the three spokes is tilted so that, as it

turns, it is inclined to its direction of motion at a certain angle of attack (compare aircraft wing). This produces lift.

Experiment 1.26. There should be a detectable lift, i.e. upward displacement of the plane, as the angle of attack is increased from a small negative value to a relatively small positive value. The values vary from model to model, but positive lift in the range -3° to $+15^\circ$ is typical.

ANSWERS TO QUESTIONS

1. Fish, and birds in flight; note relatively blunt nose and tapered tail.

2. Adjust tap and clip on outlet tubing until the ball is at any desired height. Collect the water flowing from the outlet in a measuring cylinder or any other graduated container (one graduated in pints will suit the gallons per second graduation shown in the figure) and find out, using a stop watch or clock, how long a convenient volume takes to flow through the flowmeter. Take the mean of several readings and convert to volume/second. Repeat with other settings of the ball to cover the complete meter range. Use the results to draw a graph of volume rate of flow against meter reading.

3. $5 \text{ cm}^3/\text{s}$.

4. 20 cm of water (100 – 80 cm).

5. 20 cm of water.

6. 10 cm of water/m (40/4).

7. 60 cm of water (in excess of A.P.).

8. The volume of water passing any given point in the tube in a given time is constant. Thus the volume rate of flow between D and E = the volume rate of flow between A and B. As the volume rate of flow is constant and the area of cross-section of the tube has increased, the pressure gradient must have decreased. As $DE = AB$, the pressure difference between D and E is less than that between A and B.

9. As explained in (8) the (volume) rate of flow is constant. The speed of flow in section ABC is greater than the speed of flow in section DE.

10. Assuming that the tap which controls the supply of gas to the fire is between the manometer and the fire, the reading would be 5 in of water. If the manometer were between the tap and the fire, the reading would be zero.

11. A larger bore pipe could be fitted between the fire and the main supply pipes.

12. When the bore of the pipes used is small, a relatively high

pressure difference is needed to maintain the required rate of flow. A water pump is fitted to produce this.

13. Yes.

14. It will increase.

15. The forces and so the pressures are equal.

16. The speed of the water at N is greater than the speed at W.

17. In order to maintain a constant volume rate of flow, the speed of flow must be greater in the narrower tube.

18. Bunsen: The fast flow of coal gas through the jet leads to a reduction of pressure inside the tube and therefore A.P. forces air into the tube. The mixture of coal gas and air burns at the top of the tube.

Carburettor: The constriction in the tube makes the air flow faster there and so pressure is reduced below the pressure in the float chamber. The pressure in the float chamber pushes petrol from the jet. The petrol vaporises and is carried with the air into the cylinders of the engine where it is burned.

19. Clockwise.

2 Flow of Electric Charges (pp. 15-40)

Introduction

Charging objects by rubbing them together is investigated in Experiments and Demonstrations 2.1, 2.2 and 2.3, the first and last of which lead to the same conclusions. Experiment 2.2 can be done at home.

That a flow of electricity takes place when a body is discharged is established in Demonstration 2.4. Static and current electricity are thus identified with each other.

The flow of charge when conductors touch is studied in the next section. Experiments 2.5 and 2.7, and Demonstration 2.6 produce important results. A selection may be made from Demonstrations 2.8 and 2.12 which show that this charge sharing produces like charges on the conductors concerned.

Charging by induction follows. Demonstration 2.13 and Experiments 2.14, 2.17 and 2.18 are particularly important. The alternative version of Experiment 2.16, suggested in the note on that experiment, and the making of an electrophorus are suitable homework.

The presence of ions in and around a flame is shown by Experiment 2.21 and Demonstrations 2.22 and 2.23, the first of which is the most important. Creation of ions by a red hot wire is a similar process and therefore Demonstration 2.24 may be omitted if time is short.

Demonstrations 2.25 and 2.26 deal briefly with discharge tubes. There is no need to study a large number of tubes, but it is well worth looking at two or three.

Consideration of the effect of a point conductor on the flow of ions in air follows. Demonstrations 2.27 (a) and 2.30, and Experiment 2.29 are most important.

Thermionic emission and the flow of electrons through a valve are investigated in Demonstration 2.31. That the electrons have a negative charge is shown in Demonstration 2.32.

The flow of ions in liquids is studied in Experiments and Demonstrations 2.33-2.36, Demonstration 2.34 being the least important.

Experiment 2.37 (a) is more or less a repeat of Experiment 2.7 and therefore Experiment 2.37 (b) is to be preferred for investigation of insulators and conductors.

Demonstration 2.38 is hardly essential but provides a good summary of what has gone before.

Comparison of currents in different parts of circuits which contain

resistors in series and parallel is provided in Experiments 2.39 and 2.40.

The last three Experiments, 2.41–2.43, illustrate the factors on which the size of the current through a conductor depends.

Experimental Work

Experiment 2.1. When the polythene rod is brought back near to the electroscope plate, the divergence of the leaves decreases, suggesting that the sign of the charge on the electroscope is opposite to that on the rod.

When the charged cellulose acetate rod is brought up, the divergence of the leaves increases, showing that the sign of the charge on the electroscope is the same as that on the rod.

This is probably a good point at which to draw the pupils' attention to what may happen when a charged object is brought near the plate of an electroscope carrying an opposite charge. Suppose that the electroscope is positive and the charged body negative. As the latter is brought up, electrons will be repelled from the electroscope plate to the leaves, causing the divergence to decrease. If the body carries a high enough charge, it may be able, as it is brought nearer, to repel sufficient electrons to the leaves to make them first of all neutral and so collapsed, and then negative producing divergence which may be greater than the original. Thus the end effect may be greater divergence and not less, and may be confusing to the pupil who brings the rod up too quickly and does not observe the movement of the leaves sufficiently closely.

Experiment 2.2.

(a) The balloons repel each other. Each has the same effect on the leaves of a charged electroscope when brought near it. The conclusion is that the balloons have the same kind of charge.

The only difference when the balloons are filled with a lighter than air gas is that they rise above their point of suspension instead of hanging below it.

(b) The purpose here is to encourage each pupil or group of pupils to design an experiment, but in case of difficulty, the following could be used. Balance a charged cellulose acetate rod on an up-turned watch glass and bring up a charged polythene rod to one end of it.

Demonstration 2.3. On removal of the rod the leaves diverge, showing that the mercury and thus the electroscope has been charged. When the rod is replaced the leaf divergence becomes zero, showing

that the charge on the rod was equal in size but opposite in sign to that on the mercury and electroscope.

The effect is fairly small (the greater the depth of mercury the better) and can only be seen with ease if projection is used to produce a well-magnified image of the leaves.

It has been found that the same effect can be produced, and therefore the same conclusion reached, by using a duster in place of the mercury. It should be wrapped loosely round the polythene rod and then inserted in the calorimeter. If the rod is moved up and down several times so that it is rubbed against the duster, the leaves of the electroscope diverge as soon as the rod is removed. The divergence is easily seen. Replacement of the rod leads to zero divergence.

The duster must be fairly loosely wrapped round the rod so that when the rod is removed the duster does not emerge with it.

Demonstration 2.4. The effect is most impressive when the discharge from the generator is not premature and extended as will happen if the lead being brought up to the charged generator has a sharp end, e.g. is a bare wire. If the end of the lead is connected to an otherwise insulated sphere, a spark will pass when the two spheres are close together and the resulting sharp movement of the microammeter spot will clearly link up the originally static electricity on the generator sphere with the current when it is allowed to flow to earth.

Experiment 2.5. As each extra can is connected, it takes some of the charge from the rest of the system and so the divergence of the leaves decreases. A single polythene sheet can be used in place of the blocks and it is best to have the cans at such a distance apart that the bent wires can just connect them; this provides a long base and so greater stability for the wires.

Demonstration 2.6. Any large insulated metal conductor will do. When the electroscope is connected to the globe the leaf divergence decreases as charge is shared; the larger the globe, the greater the decrease. If connection between globe and electroscope is made by insulated wire, the polythene rod will not be needed.

On connection to real earth, the leaves collapse because the earth, being able to accept immense quantities of charge with infinitesimal change in potential (i.e. having an extremely large capacity), takes almost all the charge from the electroscope.

Experiment 2.7.

(a) When the electroscope is touched the leaves collapse. This suggests that your body allows electrons to flow through it, but does

not allow you to conclude that your shoe material is also a fairly good conductor. It could be argued that the leaves collapse because charge is shared between the electroscope and your body, the latter taking such a large share that what is left on the electroscope is negligible.

To investigate the problem, it is instructive to carry out the experiment (i) standing on a good insulator such as a sheet of polythene, in which case, provided the electroscope is highly charged, the leaves will not collapse completely and (ii) touching the water tap with one hand while touching the electroscope with the other, in which case the leaves appear to collapse completely.

(b) The results are most reliable when the charged electroscope is connected, using the substances suggested, to a good earth such as a water tap. It is essential, unless the conductivity of water is being investigated, to have the substances dry and, of course, uncharged. Taking plastics quickly through a flame will remove any charge. It would obviously be unsafe to allow pupils to try to discharge some of the other materials in the same way.

Demonstration 2.8. Consider the generator to be positively charged. As the ball is brought near it, electrons will be moved on the surface of the ball, making the side nearer the generator negative and the other side positive. The attracting force between the generator and the near side of the ball being greater than the repelling force between the generator and the far side, the ball is attracted to the generator. When contact is made, electrons flow from the ball to the generator until they are at the same positive potential. As both now have the same kind of charge the ball is repelled.

Demonstration 2.9.

(a) The paper is flung off as it obtains a charge of the same kind as that on the generator, as in Demonstration 2.8.

(b) The ball is repelled for the same reason as in (a).

Demonstration 2.10. The ball, charged by induction, is unstable and is attracted towards one gong, at which it receives charge, is repelled, touches the other gong, receives charge, is repelled, etc. The ball vibrates between the gongs.

Vibration is most readily achieved when the space between the gongs is fairly small and the charge fed to them is small. Sufficient charge is usually produced by turning the generator on at a low speed and turning it off again almost immediately.

While the sound produced when gongs are used is pleasant, any insulated metal object can be used.

Demonstration 2.11. The balls are repelled by the plate and each

other and can be made to float in the tumbler. It is advisable to have a top on the tumbler, otherwise you may find that the charges are sufficient to eject the balls. Alternatively, with no top on the tumbler, ejection makes a forceful demonstration. Any clear plastic container will do. A glass beaker can also be used. A layer of aluminium foil on the bottom and a lead from the generator to the foil over the top of the container is effective.

Demonstration 2.12. The smoke disappears because the smoke particles become charged by induction and are attracted towards the central wire round which the field is strongest.

The effect can be used industrially to remove smoke particles and dust from chimneys (it is extremely important that as many factory chimneys as possible have such a device in order to reduce air pollution).

An alternative arrangement is to wind wire round a gas jar and to have the central wire suspended inside it. Wire such as Nichrome is fairly stiff even when thin and is suitable for the latter. If a little concentrated hydrochloric acid is poured into the foot of the jar, followed by a little concentrated ammonia, and the generator then switched on, the thick ammonium chloride 'smoke' is quickly cleared. If this demonstration is used, it must be emphasised that the effect is used to clear 'ordinary' smoke and not ammonium chloride from chimneys!

Demonstration 2.13. The galvanometer deflection is in one direction when the polythene rod is moved into the calorimeter and in the opposite direction when it is removed. The explanation is given in the text.

Experiment 2.14.

(a) If the partly charged electroscope has a positive charge (e.g. by induction from a polythene rod), the approach of A will cause the leaves to diverge more and the approach of B will cause them to diverge less (see note on Experiment 2.1). After being touched together A and B are found to be discharged, showing that their original charges were of the same size.

(b) The spheres are found to be uncharged as the induced charges are due to the presence of the charged rod. When the latter is removed, A and B being in contact, electrons flow back from B to A until both spheres are neutral.

Note. When an uncharged sphere such as A or B is brought up to a partly charged electroscope, the divergence of the leaves decreases. This may be explained by considering an electroscope positively charged, say. The charges it induces on an insulated conductor held near it repel electrons from plate to leaves of the

electroscope and so reduce the positive charge on the latter. The point is that it is difficult to distinguish between an uncharged body and one carrying a charge opposite to that on the electroscope. To show that a body is uncharged, bring it up close to an uncharged electroscope, when no divergence of the leaves will be detected.

Experiment 2.15. The polythene rod is negatively charged. Being earthed, the water jet is charged positively by induction (negative charges being repelled to earth) and is attracted to the rod. When the tap is turned off the electroscope continues to show a charge. When the polythene rod is brought near it, the leaves initially collapse, indicating that the electroscope and so the water has an opposite charge to that on the rod. A suitable arrangement is to put a board over a sink and to place the electroscope on it so that the water from the tap passes near the side of the calorimeter. The polythene rod can then be used to attract the stream of water so that it goes into the calorimeter. As the water collects, the leaves of the electroscope diverge.

Experiment 2.16. The explanation is given in the text. It is sometimes difficult to hold the thread steadily; suspending it from a clamp so that the ball touches the end of the rod may be considered more satisfactory.

An alternative method, which can be carried out as homework, is as follows. Lay a thin strip of aluminium foil, a few centimetres long, on an insulator such as a Perspex ruler. Place a small piece of foil on one end of the first piece and then bring up to the other end a charged rod, e.g. another Perspex ruler which has been rubbed on a jersey. The small piece of foil will fly off the larger piece.

Experiment 2.17. The electroscope has acquired a charge. When the polythene rod is removed and the electroscope then brought into contact with the bar, the leaves collapse, showing that the charges on electroscope and bar were equal and opposite.

Experiment 2.18. How the metal bar gets its positive charge is explained in the text. This can be tested by bringing the rod and bar, in turn, up to a partly charged electroscope; the leaf movements will be opposite.

It does not matter where the bar is touched. The positive induced charge is 'held' by the negative charge on the rod, while the electrons flow to earth. If the rod is removed while the finger is on the bar, electrons flow back to the bar from earth until the bar is uncharged.

Experiment 2.19. The rubbed polythene plate has a negative charge. The tin lid is charged positively by induction.

Experiment 2.20. If the electrophorus disc has a positive charge so that the pupil gets a positive charge, the temporary deflection of the galvanometer spot is due to electrons flowing to him from earth. A negative charge on the pupil would lead to a flow of electrons from him to earth.

It may be that one touch with the electrophorus disc will not give the pupil enough charge to cause a reasonable deflection on the galvanometer. He may have to be touched several times before touching the meter terminal.

Experiment 2.21. A rubbed cellulose acetate rod may be used to charge the electroscope negatively by induction. A rubbed polythene rod can similarly be used to give it a positive charge. In each case the electroscope is discharged, showing that both positive and negative ions are produced by the flame.

Demonstration 2.22. Ions are present in the flame. If the wire is connected via the Scalamp to the positive terminal of the battery, negative ions flow towards it and positive ions flow towards the Bunsen burner. Electrons flow through the circuit from wire to Scalamp to battery to Bunsen. If the wire is connected to the negative terminal, the current direction is reversed.

Demonstration 2.23. When the h.t. supply is switched on, the flame shadow (due mainly to refraction in the region bordering the flame) is broadened as positive and negative ions are drawn towards oppositely charged plates. The flame itself appears to be broader and its top is flattened. If it is not midway between the plates, it is bent towards the nearer one.

A quartz iodine lamp or other strong source, in a darkened room, make the effect easily seen. A suitable arrangement is that of a small luminous flame, about two inches high, between metal plates about four inches apart. If a 5 kV power unit is not available, a Van de Graaff generator forms a more than adequate substitute.

Demonstration 2.24. Whether the plate and electroscope are positive or negative, the heat from the wire produces ions which flow to the plates and eventually discharge the electroscope; the leaves are seen to collapse.

A few inches of Nichrome wire, about 30 s.w.g. makes a suitable coil. The exact length depends on the power supply used.

Demonstration 2.25. When the pressure is low enough (and the p.d. across the tube high enough), a glow is seen in the tube, i.e. a discharge is taking place. When this happens, a current is indicated on

the milliammeter. In air at normal atmospheric pressure, there is no detectable current (see text).

Demonstration 2.26. No comment is necessary, but teachers wishing further explanation can consult pp. 92–3 of the text, the answer to question 15 of this chapter and the note on Demonstration 7.1.

Demonstration 2.27.

(a) The flame is repelled; explanation is in the text. A large pin held lightly in a rubber-sheathed clamp can be used to provide the point. Overtight clamping may lead to leakage of charge to clamp and thence to earth.

(b) The windmill rotates anticlockwise, as viewed from above.

Demonstration 2.28. The field near the point of the nail (carrying a negative induced charge) is strong enough to ionise air molecules. The electrons released from these molecules are repelled towards the generator and positive ions are attracted to the nail. The flow of electrons to the nail in order to neutralise these positive ions constitutes the current from earth to the point.

Experiment 2.29. As the rod is brought close to the plate, the leaves diverge and when it is removed, the leaves remain diverged, unlike what would happen were there no pin on the plate. This indicates that charge has passed from the rod to the pin, via the flow of ions between them. Indeed, when the rod and pin are very close, a spark can be heard between them.

Demonstration 2.30. When the pointed metal object, e.g. a pin, is near the dome, the strong field near the point of the object causes ionisation of the air and negative charge is ‘sprayed’ (see pp. 26–7 of the text) from the pin on to the dome, reducing the charge on the latter. Thus the field between the dome and the small sphere of the generator is weakened and sparking between them stops. When the pin is near enough the dome, the field becomes strong enough to start an avalanche process and a spark passes between pin and dome.

Demonstration 2.31. When switch 1 is open no electrons are emitted by the cathode of the valve and it is unlikely that any current will be detected, no matter what the direction of the h.t. supply may be. There will be a minute current due to stray electrons and positive ions when the supply is connected as in Fig. 71. When both switches are closed, current will flow through the valve when the direction of the h.t. supply is as in the figure, but not when it is reversed. In the former case the current will be registered by the milliammeter. Thus electrons will flow through the vacuum when the power supply is connected so that the electron emitter is the cathode.

The tube is called a valve because valve is the name given to a device which will allow a fluid to flow past it in one direction only, e.g. valve in water pump and in car or cycle tyre.

As an alternative to the diode suggested, an EA50 diode will give an easily detected current with as little as 1.5 V, from a torch cell, between anode and cathode.

Demonstration 2.32. The leaves diverge as the collected ions produce a charge on them. If, with the electroscope disconnected from the Faraday cage, a charged polythene rod (negative) is brought near, the leaves will diverge further, showing that the charge on the electrons is negative.

Demonstration 2.33. When the circuit is completed before the crystals are heated, the bulb does not light, suggesting that the crystals do not conduct electricity. When the crystals have been melted, the insertion of the carbon rods does not, at first, produce any effect. Lifting the stand will show that some of the iodide has solidified on the carbon rods. Replacing the rods and continuing heating for a few seconds causes the bulb to light brightly, indicating that the molten iodide is a good conductor. When the Bunsen is removed, the bulb gradually becomes less bright as the iodide solidifies.

The addition of water to the cool solid iodide leads to the bulb glowing as the ions, now in solution, are again free to move.

Demonstration 2.34. The results are as in the last demonstration. Brown fumes at the anode indicate the presence of bromine vapour, while the silvery metal on the cathode is lead. More precise chemical identification is not required at this stage.

Experiment 2.35. The results of this experiment depend largely on atmospheric conditions and on the purity of the liquids. Dry nylon has been found to be more reliable than dry cotton as an insulator.

Typical results are:

nylon + paraffin oil → electroscope not discharged

nylon + glycerine → slow discharge

nylon + meths → instant discharge (meths is not a conductor but it will contain water, which is)

Experiment 2.36. Using pure (distilled or deionised) water, the bulb will not light. The addition of salt provides the ions needed for the current to flow through the liquid and so the bulb lights. Bubbles of hydrogen are seen at the cathode and chlorine, identified by its smell, is released at the anode. The explanation is in the text.

Experiment 2.37. (a) See 2.7 (b).

(b) The results are the same as in (a). Some pupils will be dissatisfied with a torch bulb as a current indicator; they can be given an ammeter instead.

Terminals A and B could be the halves of a plug key with the plug removed.

Demonstration 2.38. Obviously there are various diodes and neon lamps which can be used, and the choice will decide what p.d. should be applied and what range of meter should be used. A 230 V 5 W neon lamp and an EA 50 diode pass about 25 mA when about 300 V is applied using a Unilab bridge doubler. This must be maintained for a short time only as the maximum current quoted for an EA 50 is 5 mA. A lower p.d., if available, could be tried.

Demonstration 2.39. The bulbs all glow equally brightly and the meters give the same reading, indicating that the current in all parts of the circuit is the same.

Experiment 2.40. When the 3.5 V 0.3 A bulb is the only one used, it glows brightly and the three meters (f.s.d's. 1 A and 500 mA) all indicate the same current. When the second bulb is inserted, both bulbs light and the sum of the currents indicated on the 500 mA and 250 mA meters equals that on each 1 A meter. Similarly when the third bulb is inserted, the sum of the currents through the bulbs equals that indicated on each 1 A meter.

If this is done as a pupil experiment, it will probably be inconvenient to match the meters so that satisfactory results are obtained. It should then be pointed out that the accuracy of the meters will not be 100% and therefore exact answers cannot be expected. If it is done as a demonstration, it is worth taking care to match them as well as possible.

Experiment 2.41. This is *not* a suitable experiment for the verification of Ohm's law (see Experiment 10.3). Pupils should be allowed to carry out the experiment and should be encouraged to find for themselves a relationship between values of current and p.d. (the current through the bulb is directly proportional to the p.d. across it).

As the resistance of the bulb is about 12 ohms and the resistance of the voltmeter will be very much greater, the ammeter reading can be accepted as the current through the bulb. If a bulb of different power is used, an ammeter of different f.s.d. may be needed to give reasonable deflections.

Experiment 2.42. As the cross-sectional area of the carbon is increased, the current is increased. The thinnest carbon rod offers the most resistance.

As an alternative to the arrangement shown, carbon rods of circular cross-section, slipped into Terry clips of appropriate size, may be used.

Experiment 2.43. As the length of wire in the circuit is increased the lamp becomes less bright, i.e. the current is decreased. Therefore the longer the wire the greater its resistance.

It is advisable to clean the Nichrome, using emery cloth, before use.

ANSWERS TO QUESTIONS

1. See *P.I.F.* Book One, 5.9 to 5.16.
 2. See *P.I.F.* Book One, 5.3 to 5.8.
 3. See *P.I.F.* Book One, 6.3.
 4. See *P.I.F.* Book One, Chapter 6, as indicated.
 5. They will be equal.
 6. Neutrons.
 7. No.
 8. It would share its charge with the large conductor so that the latter obtained nearly all the charge. The original charged body would have so little charge left that it would probably appear to have none at all.
 9. Yes, but because the inertial mass of the Earth is immensely greater than that of the apple, the effect on the Earth is infinitesimal.
 10.
 - (a) By releasing a weight (its fall indicates the presence of the field).
 - (b) By means of suspended magnet.
 - (c) By means of an insulated suspended conductor such as a metallised polystyrene sphere.
- Discussion of the relative sizes of the fields concerned could well take place at this time, the extent depending on the calibre of the pupils. It could be pointed out that, while the gravitational field would seem to be much more easily detected and so much larger than the others: the latter can be made large enough to overcome the gravitational field at the Earth's surface; the gravitational field of the Earth decreases with distance from the surface; gravitational forces between particles in an atom are very much smaller than the electric forces there, etc.
11. Either that the field was zero or that the detector was not sufficiently sensitive.
 12. Straight lines at right angles to the Earth's surface, radiating from the centre. There are very small variations due to the nature and shape of the Earth's surface.
 13. A negatively charged body.

14. A positively charged body.

15. As the pressure is reduced, the average distance between the gas molecules becomes greater and therefore the average distance the electron travels between collisions becomes greater. As it is acted on by an approximately constant force, it accelerates uniformly and, on average, reaches a higher speed and so attains higher energy before hitting a gas molecule. Thus the chance of an electron having enough energy to remove another electron from a gas molecule increases as the pressure decreases and an avalanche becomes more likely. See note on Demonstration 7.1 (a).

16. The most common one is sodium vapour; mercury vapour is also used. See note on Demonstration 7.1 (b).

17. It is converted into heat. A tungsten lamp in use is hot; a discharge tube is cold.

18. Yes.

19. The water molecules are uncharged.

20. The cathode.

21. Positive.

22. This is because, on average, P, Q and R are feeding six cars per second into S.

23. Adjusting the rheostats will cause different currents to flow through M_1 , M_2 and M_3 . M_4 will read the sum of these currents. Thus, within limits, various 'numbers' can be produced on M_1 , M_2 and M_3 , their sum being indicated on M_4 .

3 Flow of Heat (pp. 41–50)

Introduction

Experiment 3.1, which could either be done at school or at home, provided one assistant is available at the latter, establishes that gravity is responsible for flotation. It may be considered that the logic behind this experiment is too difficult for the majority of pupils to follow and that as flotation has already been considered in Chapter 9 of Book One, pupils may reasonably understand convection without it.

That a confined lighter than air gas or hot air tends to rise in cold air is shown in Experiment 3.2, preparatory to investigating the rise of unconfined hot air in the two experiments which follow; of these, Experiment 3.4 could be set as homework.

Convection in liquids is studied in Experiments and Demonstrations 3.5–3.8, of which 3.6 is probably the least important.

Demonstrations 3.9–3.13 show the temperature gradient in a solid rod when heat is being conducted along it and illustrate the factors on which the rate of conduction depends. This is a very important link between the flow of fluid through a tube (1.7–1.12) and rate of flow of electric charge (2.41–2.43).

Differences in the conducting ability of some solids, and hence some practical applications, are dealt with in Experiments 3.14–3.16, the first being the most important.

Conduction by water and air, leading up to the use of air as an insulator, are considered in Experiments 3.17–3.19.

Demonstration 3.20 introduces heat radiation, to be investigated at greater length in Chapter 8.

Experimental Work

Experiment 3.1. Imagine the bottle at rest, say on a bench in the lab, with force F_1 acting vertically down on the top of the cork and F_2 acting vertically up on the bottom. F_1 and F_2 are due to water pressure plus atmospheric pressure. When the cork is at the bottom of the bottle, $F_2 - F_1$ is greater than W , the weight of the cork, and so the cork, if released, will rise. But F_1 , F_2 and W all arise because of gravity and therefore, when the bottle is allowed to fall and gravity inside the bottle has apparently disappeared, the cork should not tend to move. This, in fact, is what is observed.

To demonstrate apparent 'weightlessness' during free fall, ask a

boy, holding a spring balance with a mass attached, to jump from a bench to the floor, observing the balance as he does so; it reads zero.

Experiment 3.2. The balloon will rise if the total weight of its material and its contents is less than the weight of the air it displaces; likewise with the bag. To reduce fire danger, a bag at least 25 cm in diameter should be used. Smaller bags can be used but the element of risk is increased. If insufficient air is displaced, by not blowing the balloon big enough or not replacing enough cold air with warm air in the bag, the balloon or bag will not rise.

Experiment 3.3. As the air heated by the flame expands, becomes less dense and rises, cold air comes in from the sides and below to take its place and, in turn, cold air is drawn through the door. The movement of the air is indicated by the smoke moving along the bottom of the box and up the chimney.

The more familiar box with two chimneys, the candle being at the foot of one of them, can also be used to illustrate the point. A wax taper (or tapers), freshly blown out, provides smoke.

Experiment 3.4. As the air heated by the flame rises, a draught which is predominantly vertical moves upwards through the spiral. As each section of the latter is inclined to the horizontal, the air rising past it is deflected to one side, causing the spiral to be deflected in the opposite direction (conservation of momentum). The direction of rotation is with the lower end of the spiral leading.

At this stage it might be worth while pointing out that the rotation of a turbine is caused in a similar way and that the forward motion of a propeller-driven aircraft is due to the slanted blades of the propellers giving air momentum towards the rear of the aircraft.

To avoid scorching, the top of the spiral should be at least 10 cm above the top of the candle, assuming the latter is large. If birthday cake candles are used, this height can be reduced. It has been found that having the suspension point slightly off centre produces a faster rotation.

Experiment 3.5. This is a striking demonstration. Convection currents are easily seen. A weak solution of any of the wash-up liquids and a pinch of powder produce good results.

Experiment 3.6. A stream of hot (coloured) water rises from the narrow glass tube and floats at the top of the beaker. For success, make sure that the ink bottle and its tubes are completely free from air bubbles.

Demonstration 3.7.

(a) When the cover glass is removed, the cold coloured water

moves down one side of the lower jar while the hot clear water rises up the other side of the upper jar.

(b) When the cover glass is removed, the hot and cold water remain in their respective jars.

The cold water being denser than the hot water, the arrangement in (a) is unstable and so movement takes place, whereas the arrangement in (b) is stable and no movement takes place (diffusion and cooling will, of course, gradually lead to mixing).

The removal of the cover glass causes some spilling, with a tendency to spoil the stability in (b) and it has been found that a piece of fairly stiff, thin card is more satisfactory than the glass.

Demonstration 3.8. If permanganate is used, water is a suitable liquid for the system. It is important to add the permanganate after the convection has been established, otherwise the water becomes uniformly coloured too quickly for circulation to be clearly seen.

Demonstration 3.9. The graph of temperature against distance is not a straight line, as in the case of pressure against distance in water flow, but a curve as indicated in Fig. 105. Near the hot end of the bar, more heat will be lost by radiation than near the cold end and so a greater temperature difference will be associated with two points, a given distance apart, at the hot end.

Mercury in the holes in the bar will produce good thermal contact between thermometers and copper.

Although not quite so effective as the apparatus illustrated, a bar directly heated (gently, unless you are using high range thermometers!) at one end, with a wet cloth wrapped round the other, the ends of the cloth dipping into a beaker of cold water, shows the required effect.

Demonstration 3.10. The temperature difference is greater across the dibutyl phthalate rod (used because of its high boiling point), and so, as the length and area of cross-section, the other important factors, are the same for each rod the ice melts more quickly at its end.

The greater the temperature difference between the ends of a rod, the greater the rate of flow of heat along it.

Demonstration 3.11. The rate of melting of ice is greater at the end of the wider bar. Therefore the rate of flow of heat is greater through the wider bar.

Demonstration 3.12. The rate of flow of heat is greater through the shorter bar. Although the temperature difference between the ends

is the same for each rod, the temperature gradient is greater in the shorter bar; hence the rate of flow of heat is greater.

Experiment 3.13. The rate of flow is greater through the better conductor, in this case the copper.

Experiment 3.14.—an excellent 'observe and explain' experiment.

After the gas is lit below the gauze, it is some time before the gas lights above it, because the gauze conducts heat quickly throughout itself and then loses it to its surroundings almost as quickly as it gains heat from the flame. Similarly, when the gas is lit above the gauze, it does not immediately light below it.

When the air hole is open, the delay in each of the above cases is greater than when it is shut.

A paraffin heater used in a garage has wire gauze round the flame to prevent any petrol vapour which may be present being raised to a high enough temperature to make it burn.

Similarly a Davy safety lamp, formerly used to give light in a coal mine, has a wire gauze round the flame to prevent the explosion of methane.

Experiment 3.15. The drawing pins conduct heat away from the paper where they touch it. When the rest of the paper becomes charred, the paper touching the pins is not charred.

Experiment 3.16. The penny feels hotter than the asbestos because, the metal being a better conductor than the asbestos, heat travels more readily to the finger from it, the heat initially taken by the finger being replenished quickly by conduction through the metal. Hence there is a quicker flow of heat into the finger.

Concrete feels colder than wood at the same temperature, because it is a better conductor of heat (thermal conductivity of concrete is six or seven times that of wood).

Experiment 3.17.

(a) When the water is heated near the top, the reading on B is far below 100°C when T reaches 100°C . When the water is heated at the bottom, T reads slightly less than B when the latter reaches 100°C .

The first experiment shows that when little or no convection takes place (refer back to Demonstration 3.7) the transfer of heat through the water is slow, i.e. water is a poor conductor of heat. The second experiment shows the difference when convection takes place.

It might be better to do the second experiment first, at the end of it posing the question 'Does this prove that water is a good conductor of heat?' and when the negative answer is received (we

hope!), leading round to how the procedure could be adapted to reduce the effect of convection. The first experiment, with the original hot water poured out and fresh cold water substituted, then follows.

Although Fig. 111 suggests that the experiment can be carried out by one pupil, there is a fair amount of manipulation, observation and noting down of results, so that at least two pupils should work together.

(b) The ice will not have melted by the time the water has started to boil at the top.

(c) This is similar to (a). The water at the bottom takes a long time to become hot.

Experiment 3.18.

(a) The results are similar to those for water in part (a) of the last experiment, showing that air is a poor conductor of heat, but it has been found that the dimensions of the tube have an important bearing on the success of the experiment. A tube eleven inches long and one inch diameter showed very little change in the bottom thermometer reading altogether the top temperature reading had risen 30°C , but then showed precisely the same answer when the tube was heated near the bottom: there was little detectable rise at the top! Investigation with different lengths and diameters led to the conclusion that a tube of fairly large diameter, at least two inches, and of length about eight inches was very satisfactory. Various other shapes were acceptable, but long thin tubes were unsatisfactory.

(b) Care required!

Experiment 3.19. The unlagged calorimeter loses heat more quickly, indicating that the trapped air round the lagged calorimeter is a good insulator.

Demonstration 3.20. After hand heating, the water is pushed up the tube by atmospheric pressure acting on the water in the dish. The action of the radiator heats the air in the flask and the water is pushed down the tube as the pressure in the flask increases. Previous experiments have shown that the effect cannot be due to conduction or convection. It may be suggested by pupils that the heating of the air may be due to absorption of light by the flask and the last part of the experiment is designed to answer this criticism. That light has some effect is shown by the fact that the water level does not fall to its original level when the radiator is emitting infra-red radiation only.

An infra-red lamp has been found to be highly satisfactory as the radiator. It should be placed a few inches above the flask.

This presents another excellent opportunity for pupils to observe

and then to explain what has happened. In addition to the various stages of the experiment described above, they should observe that when the thermoscope is heated, the water level *rises* before it falls; they should then be encouraged, if necessary, to produce the explanation that this is due to the initial expansion of the flask.

ANSWERS TO QUESTIONS

1. Dust is carried to the walls by the convection current set up by the radiator.

2-3. Generally, near the bottom, so that its action would set up convection currents which would cause all the water to circulate past the heater. However, if a small quantity of hot water is needed, it is wasteful to heat the whole tank and for this, a small additional heater near the top is often used. The water heated by it does not circulate, but stays at the top of the tank from which it can be drawn off.

4. (See Experiment 3.3.)

5. The departure of hot air up the chimney demands the arrival of displacement air at the fire. This in turn requires that fresh air be drawn into the room from outside, e.g. via a window or under a door, or through specially constructed vents in walls or floor.

6. In the deep freeze, the cold air being denser than the air above it, has no tendency to rise and leave the freeze. In the Thermos flask, the air above the tea is less dense than the air above and so it rises, being replaced by cold air which is warmed by the tea before rising from the flask. Thus a continuous convection current of air into and out of the flask takes heat from the tea.

7-8. It could be, but no conclusion can be reached for the heating could be due mainly to convection. Experiments have to be carried out to solve the problem (see Experiment 3.17).

9. Air is trapped in the holes of the vest. Circulation, i.e. convection currents, are greatly reduced and so heat is not removed from the body by this method.

10. The snow (ice) is a poor conductor of heat.

4 Waves (pp. 51–62)

Introduction

Experiments 4.1, 4.2, 4.5, 4.8 and 4.9 serve to introduce pupils to the character and terminologies of waves—wavelength, frequency, amplitude, etc.—and to the relation $v = \lambda f$. When the ‘Slinky’ is out, some may care to include at this stage the characteristics of transverse and longitudinal waves (Experiment 5.1).

Demonstrations 4.4, 4.6 and 4.7 are excellent only if they are available in the school with laboratory technicians to set them up, but valuable class time should not be lavished on them.

The ripple tank. This work is vital and should not be rushed, *every* pupil being allowed individually to ‘play’ with these waves, investigating reflection, refraction, diffraction and the all-important interference patterns as suggested in Experiments 4.11, 4.12 (*b*), 4.14, 4.15, 4.17 (*a*) and 4.18. Experiments 4.13 and 4.16 are perhaps extras for the quicker and abler pupils. Another ‘extra’ which may be useful later is for pupils to investigate reflections from a curved reflector, leading to the idea of a focus. The ripple tank (or 8 mm loop film) analogies should be referred to again and again as its relevance becomes apparent in Chapters 5, 6 and 7.

Experiments 4.19 (cf. 5.43) and 4.20 (cf. 7.14, 7.15 and 6.3 (*f*)) can be performed as indicated at this point either alone, as suggested, or together with those referred to in the brackets or postponed until work is done on sound and light. Here again there is a choice in that interference can be tested before studying sound or light (i.e. at the *beginning* of each chapter) or in the order the text suggests.

Questions 3, 4, 5 or 6 can be set for homework and pupils can be asked to draw at home various ripple tank patterns they have seen at school.

Experimental Work

Experiment 4.1. Pupils should notice the wave being reflected, on the opposite side of the rope and with the amplitude gradually decreasing.

Experiment 4.2. Using the coil or ‘Slinky’ should confirm the above findings but pupils might be encouraged to notice the different speeds of the pulses for different tensions and the motion of any one coil in comparison with the motion of the wave.

Demonstration 4.3. The reflected pulse is *not* on the opposite side of the spring. A little energy is transmitted along the thread.

Demonstration 4.4. It will be found that considerable care will be required in the construction of this machine, if clear success is desired—the exact position and balancing of the nuts being essential. The nuts will vibrate slowly in a horizontal plane as the wave pulse moves up the rule. The reflected pulse returns on the opposite side if the upper strip is clamped firm.

Experiment 4.5. The discussion hinted at previously and dealt with here should bring out the difference between the motion of the particles vibrating about a fixed point and that of the energy being transmitted by the wave (this could flick into movement an object placed at the far end of spring or tube). The discussion might further elicit from the pupils the two opinions that if the dwarf securely clutched the tube he would vibrate, but not travel, whereas if he had slippery pants he would not vibrate but would slide forward at v cm/s.

Any of the following three experiments give further supporting evidence.

Experiment 4.8. If the pupils are ranged along the full length and on each side of the 'Slinky' they can mark the points of interest. They should see the waves passing through each other. This may be clearer if the pupils at each end send down waves of markedly differing amplitude. With care, however, if the initial jerks are in opposite directions and of nearly equal displacement (strength?) a pupil holding his finger above the point where the pulses meet should show a null displacement.

Experiment 4.9. This is deliberately given as an experiment, affording an opportunity for pupils to discover for themselves the possible ways of increasing the tension or shortening the tubing.

Demonstration 4.10. Pupils having sensed the possibilities qualitatively, a simple integral relationship can now be demonstrated in the manner described, showing the doubling of the frequency and the halving of the wavelength: three times the frequency giving one-third of the wavelength. It can be made more spectacular still if the room can be darkened.

Note. Water-waves: Some authors maintain that the positioning of the light source is critical and that its filament should be aligned with the (plane) wave fronts. This may be so for quantitative work with a ripple tank, but for the qualitative experiments described here,

pupils can position the light source anywhere that is convenient for their seeing the 'shadow' patterns.

Experiment 4.11.

(a) The circular wave spreading out evenly suggests that its speed is the same in each direction.

(b) The reflected wave front should suggest where the 'virtual source' would be situated. Pupils can be invited to check this by removing the barrier and touching the water surface at the estimated point and noting the similarity of the wave pattern.

Experiment 4.12. If the paper placed under the tank has radial lines drawn at 10° intervals with point of rotation of this wood as centre drawn, this may help in the positioning of the reflector and in elucidating the hoped-for results. The waves do not bend nor alter in f , λ and v .

Experiment 4.13. If a flashing strobe is not available the teacher may not consider worthwhile the difficulties involved in measuring the frequency with a hand strobe for the rewards of this exercise.

Experiment 4.14. The slowing up of the waves in shallower water should be discernible, as should the decrease in wavelength; a hand strobe might confirm the constancy of the frequency. When the plate is raised, it should be wedged and not held by hand. Coast-dwelling pupils might be encouraged to discuss the reasons for the breaking of surf waves (even on windless days) and its relevance to coast erosion and methods of coast preservation.

Experiment 4.15. This introduction to the focussing action of a lens should show the changing of direction of the waves at the boundary, continuing thereafter in their 'new direction', with new λ and v , to the next boundary.

Experiment 4.16. Waves should not stop at F but be shown to continue *through* and spread out beyond this focus.

Experiment 4.17.

(a) Provided the gap is smaller than the wavelength chosen, the spreading curved waves and diffraction patterns should be clearly seen as semi-circles. Long waves are 'bent' more than the short.



FIG. 30

(b) Objects smaller than the wavelengths make little or no difference to the waves (Fig. 30).

Experiment 4.18. Pupils should be encouraged to look for any possible interference patterns. The easiest to detect are probably those from the method described in 4.18 (a), but they have been found by youngsters dabbling two fingers simultaneously, and by noting the interference between the direct and reflected waves from a beam, for glancing angles (Lloyd's mirror, in optics!).

Experiment 4.19. If the teacher sets up this experiment and tunes it himself, so that interference in the two tubes causes a minimum of sound, pupils should have no difficulty in hearing the increase in sound when one tube is pinched. If they have understood the meaning and significance of the previous important ripple tank experiment they should have been able to establish the wave nature of sound.

Experiment 4.20. A variation on the method suggested here is to use as alternative light sources, ray boxes, one giving red light, the other blue (using coloured celluloid). The band structure is clear and the spacing between the single-coloured bands is different. Light behaves like water waves in showing interference.

ANSWERS TO QUESTIONS

1. It is reflected on the opposite side or on the same side respectively.
2. They are equal in size and opposite in direction.
3. Submerge to avoid the distressing surface wave effects.
4. It bobs up and down, but is not moved horizontally. Children will claim that they can cause a cork to 'come ashore' by throwing stones beyond it. In discussing this apparent paradox they should be reminded to look more carefully for an explanation, e.g. splashing effects, and wave breaking, etc.
5. They are equal.
6. $v = \lambda f$.

5 Sound Waves (pp. 63–87)

Introduction

Experiments 5.1, 5.3, 5.5, 5.8 and 5.9 will give some understanding of the production of sound waves. Experiment 5.4 would be great fun for a club activity and 5.6 and 5.7 could be set as homework projects.

If time is at a severe premium, the concept of resonance can be omitted at this stage and dealt with when pupils are older—Experiments 5.10–5.21 postponed.

Demonstrations 5.22 and 5.23 will elucidate the ideas of quality of sound, while Experiments 5.26, 5.27 (b), 5.30 and 5.33 will show its transmission through various media, 5.34 (a) or (c) and 5.36 showing how its speed may be determined.

Care must be taken by teachers to ensure that the above familiar and enjoyable work is not allowed to take up so much time that the following experiments are omitted or ‘skimped’; they are important for the coherence of this part of the work: Demonstrations 5.38, 5.40, 5.41 and Experiment 5.43, together with reference to ripple tanks or film loops.

Experiments not referred to above can be set as homework projects—5.25, 5.29, 5.30, 5.32, 5.37, 5.39 (b), 5.42—or as club activities, 5.24, 5.28, 5.31, 5.35, 5.44, 5.45.

The final five pages on detection and reproduction of sound and on ultrasonics could be a period where pupils could follow up personal interests either by home preparation or with club assistance (Experiments 5.46–5.49) to prepare lecturettes by pupils together with a showing of the recommended films.

Resonance: Should the teacher wish to include a brief reference to resonance, as in the text, Experiments 5.12, 5.14 (5.15), 5.17 (and 5.19) should convey the ideas, with 5.11, 5.15, 5.19 and 5.21 set for homework.

Experimental Work

Experiment 5.1. A single compression pulse will be reflected back from the fixed end as a compression pulse; when a series of these is sent down they will be similarly reflected, but pupils may be encouraged to look out for any interacting effects, e.g. incident

pulse meeting reflected pulse. The coils of the spring move in the direction of the travelling (pulse) wave.

Experiment 5.3. The movement of the ball, the splashing of the water and Fig. 147 should clearly indicate the vibration of the prongs of the tuning fork.

Experiment 5.4. This amusing trick might first be introduced (without explanation) as a spectacular demonstration. Without waiting for anyone to 'see through it', tuning forks could be distributed with an invitation to anyone in the class to repeat the effect. Once this is achieved (with help if necessary) simplified explanations can be asked for, e.g. more molecules (in the bench) are now vibrating. There should be no reference to the word 'resonance' at this early stage.

Experiment 5.5. The sound clearly increases with the amplitude of vibration.

WARNING. Loudspeakers, oscillators and/or amplifiers can be easily overloaded to breaking point in this type of experiment. The amplitude should not be increased more than is necessary to show the effect.

Experiment 5.6. In all of these cases the sound (vibration) ceases on touching.

Experiment 5.7. Able children who find a method and an answer for this experiment considerably quicker than their classmates might be challenged to devise a second method to check their own answer.

The basis of a simple method however might be to turn the wheel round one revolution (or a known fraction) at speed slow enough to count the separate clicks of the card; thereafter, count the revolutions of the wheel in a measured time; the product of clicks per revolution and the number of revolutions per second give the frequency. The question could be posed as to whether or not, at higher speeds the card clicks over *each* bump, as it did at the lower speeds—and how this might set an upper limit to reasonable accuracies. If it is desired to avoid this difficulty for a poorer class, using the spokes of the wheel instead of the tyre tread might help.

Experiment 5.8. Even as a home-made siren the rise in pitch of the note can be heard. Determination of frequency is similar to that for Experiment 5.7. For able pupils not only can the question of too short a time interval for measurement be mentioned but one can consider the longest, reasonable time interval to choose—governed

by how long the disc can be rotated steadily at a given rate (with higher notes the sensitivity to change can be quite marked).

Experiment 5.10. Although other pendulums may move in a minor and irregular way, only the pendulum of equal length to the 'driver' will begin to swing like it. The effect is most spectacular when the suspending string is as taut as possible—using heavy weights or G clamps on the bases of the retort stands.

Experiment 5.12. The higher the frequency the shorter the length of vibrating strip.

Experiment 5.13. After doubling the frequency to obtain the second harmonic, the text indicates results to be expected.

Experiments 5.14–5.17. These experiments give similar length and frequency effects for air columns. In Experiment 5.15, care should be taken to use a fairly well-angled cut to obtain a long enough vibrating 'reed'.

Experiment 5.18. (b) With the tube horizontal no sound is heard as convection effects cannot now operate along the length of the tube; if the gauze is still hot enough, on restoring the tube to the vertical, the sound will again be heard.

Experiment 5.19. The resonating length of air column is usually easily heard in the second bottle.

Experiment 5.20. Various sources should be mentioned—vibrating lips (bugle), single reeds (clarinet), double reeds (oboe). Bagpipes and pipe organs will show both types of reeds and the longer lengths of air column producing lower notes—even to the threshold of pain!

Demonstrations 5.22–5.23. A suitable microphone recommended by Nuffield (N.157) should show the variety of waveforms on the oscilloscope screen.

Experiment 5.25. A member of a 'group' (at least one in every school!) would no doubt be pleased (or prevailed upon) to demonstrate these effects.

Experiment 5.33. If it has been found that sound travels through solids, pupils should have no difficulty in suggesting how the bell may yet be heard via the elastic bands when the air is pumped out. Possible follow-up homework questions might be to devise means of

further improving sound insulation—for this experiment and in practical situations such as house-building.

Experiment 5.34.

(a) Provided a suitable environment (as described in the text) is available this experiment can be performed simultaneously by groups standing about 15 m apart. The possibility of confusion could be reduced by the precaution of having each pair of blocks give a different quality 'note'. Youngsters are likely to enjoy getting out of doors and amusing themselves in this way, but if worthwhile results are to be obtained the teacher should take particular care in ensuring they do understand the meanings of their figures and how to use them—in the example quoted, 2 seconds between claps, one second for the time and 360 yards (1 080 ft) for the distance of sound travel to and from the wall.

(b) The assumption of a very high speed for light may be asked in (c) which may be the more practicable experiment. Here again great care must be taken to ensure that the meanings and manipulation of readings are clearly understood.

When the blasts are heard between flashes sound is taking 0.25 seconds to travel to you. When flash and blast are received at the same time, 0.5 seconds has elapsed.

Experiment 5.35. The frequency produced by a whistle depends on λ and v ($f = v/\lambda$). The wavelength depends on the physical length of the whistle, which remains the same, so that the frequency is proportional to the velocity of sound. In this experiment the note rises in pitch when hot air is blown into the whistle showing that the speed of sound is greater in the less dense hot air.

Experiment 5.36. If 2 m of Bunsen tubing are used the rise in pitch is sufficiently delayed for a striking effect, when the coal gas eventually reaches the whistle. Disconnect the tube from the gas supply and blow through it. The drop in pitch is again noticeable when the exhaled air has driven the gas through and out of the whistle. This experiment, showing increased speed of sound in the less dense gas, can be referred to when seeking an explanation to the effects seen in Demonstration 5.40.

For Experiments 5.38–5.44 occasional revision of the ripple tank experiments or 8 mm loop films may be useful.

Demonstration 5.38.

- (a) The angle of incidence and angle of reflection are equal.
- (b) The hard, smooth substances reflect most sound.

Demonstration 5.40. In this experiment (related to Experiment 5.36)

care should be taken to fill the balloons to the shape required for a good focus—nearly full to a pear shape. It is possible to show that a focussing effect is produced with the balloon filled with carbon dioxide because of its greater density; the speed of sound is less in the denser gas.

Demonstration 5.41. The diffraction effects can be detected by ear although the bending at higher frequencies may be more difficult to discover without the aid of the microphone arrangement.

Experiment 5.42. The high frequency noise produced by rubbing finger and thumb does not bend round the head and so cannot be heard in the middle of the room. It is reflected in the corner and therefore it can be heard there. The keys produce lower frequencies which can bend round the head and so be heard in both positions.

Experiment 5.43. A striking experiment related to this was shown in the BBC TV series *How and Why? An enquiry into physics teaching*. All the members of a class were asked to move around in an open field in which two loudspeakers were set up about a metre apart. They were asked to listen to a 1 000 c/s note and then to stand still in any chosen position of maximum sound. When all had settled to their chosen positions, the fan-shaped loci of the interference pattern was discernible.

Experiment 5.45. The sound waves cause the diaphragm to vibrate at the frequency of the sound.

Experiment 5.46. Although a microammeter is preferable, as recommended in the text, a demonstration milliammeter (e.g. (N. 70) 71/4 on 2.5–0–2.5 mA) may be used. The frequency of the induced current is the same as the frequency of the moving wire.

ANSWERS TO QUESTIONS

1. He would vibrate backwards and forwards in the direction of red arrow.

2. In theory, yes; in practice it is difficult not to include some transverse motion.

3. Probably best illustrated by displaying on a C.R.O. screen: a note usually produces a much simpler wave trace than a noise, i.e. the variety of frequencies contributing to the note is less complex than that for a noise.

4. No, it did not. If necessary illustrate by sprinkling some cork

crumbs or light powder on the water surface of a ripple tank, near the rippler.

5. The turns vibrated about a mean position, but did not move along the coil.

6. If the noise of breaking waves or of a bath running out are quoted as examples, it should be pointed out that the noise (carried through the air or solid) is probably due to the motion of the liquid *surface* rather than its bulk. This may be illustrated trying to 'hear' water flowing through a tube. Most noise will be heard where the water emerges from the tube—very little from the full portion of the tube. It might be an interesting variant to allow various amounts of air bubbles to be included in the flow to see what effect this has on the 'sound of flowing water'.

7. The following text indicates that there are sounds we cannot hear—at ultrasonic frequencies and at very low frequencies.

8. There is a Standing Order for all soldiers to 'break step' when crossing bridges; this means there is no longer a regular frequency of all feet beating in time together on the bridge but a random patter to avoid the build up of resonant energies.

With reference to the following paragraph (the Tacoma Bridge) it is interesting to note that for the Forth Road Bridge, vents have been left between the road carriageways and the pedestrianways to allow the wind 'through' the bridge, and for the Severn Bridge, the edges have been aerodynamically shaped to reduce the likelihood of gusts of wind setting up a resonance effect and another disaster.

9.

(a) For tuning, he adjusts the tension by means of the appropriate pegs at one end of the guitar.

(b) While playing, he varies the length of the strings by placing his fingers at different points along its length using the appropriate frets.

10. The low notes require less tension and longer strings than do the high notes. This is particularly noticeable in a grand piano where not only are the differing lengths obvious, but, on inspection, the different types of wire may be seen.

11. A highly skilled player can use various subtleties, but the more obvious and more generally used one is the difference between plucking (or even caressing) the string with the fleshy ball of a finger and plucking it with a hard fingernail or plastic plectrum.

12. This is not necessarily a case of the recorder replaying at a slower or faster speed. One usually hears one's own voice not only by reflection through the air (speaking in an anechoic room is somewhat startling) but by transmission of vibrations generated in the voice cavities through the bone connections to one's ears. This method of transmission can, and usually will, transmit a different pattern of frequencies from those which the vibrating air column

will transmit. The microphone, and hence recorder, will only detect the latter and hence on reproduction from the device one hears one's own voice without the frequencies normally transmitted within oneself (via bone, etc.).

13. Longitudinal waves.

14. Taking the speed of sound as 1100 ft/s, the thunderstorm is 11,000 ft distant (approximately 2 miles).

15. As well as assuming a chosen value for the speed of sound in air, the speed of light has been ignored, i.e. it has been assumed to be near infinite.

16. $v = \lambda f$, hence the frequency would be increased, i.e. the pitch would rise.

17-18. Under ideal conditions only the low notes (trombones, drum, etc.) would be heard round the corner and the high notes (flutes, piccolos, etc.) would not. These ideal conditions presuppose that these extremes of notes will be produced with the same volume (amplitude of vibration at source), that there will be no opportunity of the waves being *reflected* round the corner (e.g. from other buildings) and that the solid corner of the lone building will not transmit through it any appreciable amount of sound. As these conditions are rarely met with in practice alternative answers may be expected and may be correct if founded on personal experience. A discussion of explanations could ensue.

A related factor which may crop up in the discussion is the well-known experience of anyone trying to sleep in a room near another where a real or recorded dance band is playing—the sound most readily transmitted through the (solid) building is the dull, repetitive thud of the drum and double bass. This of course has nothing to do with diffraction effects—the point of the questions—but may affect the answers supplied by children from their experience.

19. The choice of starting and stopping places in this chain of transformations is arbitrary, but the chain may include:

potential energy	(finger pulling against tension of string)
kinetic energy	(vibration of released string)
sound	(vibration of molecules in air)
mechanical	(vibration of microphone diaphragm)
electrical	(via microphone)
mechanical and sound	(vibration of loudspeaker and air)

The more able child may question the significance of the word 'amplified', where more electrical energy is fed in (from another source) to provide a larger mechanical and sound energy at the final stage than originally, i.e. a louder sound.

20. Carbon microphones are cheap and robust. They are used in most telephone mouthpieces. Crystal microphones are often used with tape recorders. They give better quality reproduction and are relatively cheap. They are however fragile.

21. The moving element in a microphone is easily knocked out of alignment. This is particularly true of the ribbon microphone. Crystal microphones and moving coil microphones can also be fairly easily damaged by rough handling.

22. The answer to this question should have been obtained from the earlier Demonstration 5.9.

23. As the speed of sound in water is approximately 5,000 ft/s, the frequency would be $f = v/\lambda = \frac{5000}{0.1} = 50,000$ c/s.

6 Electro-magnetic Radiation (pp. 88–94)

Introduction

All the demonstrations of the short Chapter 6 should be performed, with the emphasis on the important number 3. In the interests of time, the work of Chapter 8 could be covered simultaneously, with a selection from the eight experiments suggested.

Experimental Work

Experiment 6.1. The projection of the spectrum from a white light source should follow standard procedure. The infra-red detector may be obtained commercially (N.68) or may be home-made as described in the text on p. 110.

With the bulb switched on, radiation can be detected just beyond the red end of the spectrum. This disappears when the bulb is switched off. A prism filled with carbon disulphide (cf. 8.4) gives rather better results.

Experiment 6.2. The clicking noise is quite audible. Pupils may be encouraged to discuss similar effects with interference on television screens at home from older models of various domestic electric appliances and the part played by 'suppressors' (see *P.I.F.*, Book Four, Ch. 8).

Demonstration 6.3. The series of experiments described here are well demonstrated in the Esso film for science teachers *The use of centimetre waves in teaching optics*.

(a) Although sixth year students may well investigate dispersive and other effects, for younger pupils it is sufficient to show straight-line propagation and the fact that the signal strength falls off rapidly with distance.

(b) A metal sheet should cut off the signal; a thin paper sheet should not noticeably affect the signal. The effective order of other materials between these limits will probably depend on the types of material used, but if scrap pieces are used it is more than likely that thicknesses will be different.

The explanations sought are those of reflection and absorption—although again the point about thickness should not be overlooked.

(c) When symmetry is achieved the signal strength suggests that the laws of reflection are obeyed—but does not necessarily confirm this to be a wave radiation.

(d) The radiation is indeed refracted, the direction of the refraction, suggesting it is slowed down in paraffin.

(e) A signal can be detected outside the mere geometrically direct possibility showing that there is bending round the edges of the slit.

(f) This is the key experiment (possibly together with (e)) which confirms the wave nature of the radiation.

(i) A series of maxima and minima can be detected; reference to similar ripple tank phenomena will explain why. This is probably the simpler example of interference with its closer analogy to the two-point source in the ripple tank.

(ii) This example is more like the standing waves analogy in springs or rubber tubing. Again maxima and minima may be detected as the incident and directly reflected signals interfere constructively or destructively.

Experiment 6.4. The filament glows more and more brightly as the resistance is reduced.

Demonstration 6.5. Care should be exercised in the use of ultra-violet rays. Where pupil participation is employed in the manner suggested (always a popular move), exposure to the rays should only be for short periods. The explanation asked for follows from that given earlier in the text.

Demonstration 6.6. Not every school may have easy means of producing X-rays. Where immediate production is impossible, co-operation with local hospitals may yield old X-ray tubes and photographs for display.

Demonstration 6.7. Schools tackling more serious work later on radioactivity will probably be able to demonstrate a gamma ray source and detector. Those who do not contemplate such work may be able to seek the co-operation of a local Civil Defence unit. Only safe X-ray equipment should be demonstrated in schools. Teltron now supply such X-ray apparatus.

ANSWERS TO QUESTIONS

1. The energy comes from the received signal of electromagnetic waves—generated in the transmitter.

2. This tells us that electromagnetic waves, like other waves, can transmit energy.

3. The longer the wavelength, the greater the bending of the waves.

4-5. The longest possible, hoping the transmitted waves would be

bent or diffracted sufficiently to enable all the 'hidden' towns to receive the radiation.

6. The semi-mechanical means such as a Crookes radiometer (see p. 114) are probably of only academic interest and need not be discussed here. Examples could come from photochemical effects—the eye, photographic plate or film, photosynthesis—or from photoelectric effects—phototransistors, camera exposures meters, etc.

7. Potential energy.

8. One pushes or pulls the box against a gravitational attraction (force).

9. Some into sound energy, most into heat energy, dissipated in the surroundings.

7 The Visible Spectrum (pp. 95–109)

Introduction

Experiments 7.2, 7.5, 7.7, 7.10, 7.11, 7.12 (a), 7.13 and 7.15 will cover the vital points of this chapter, if supplemented by homework projects 7.3, 7.4, 7.6, 7.8, 7.9 and 7.12 (b).

Pupils should be given some idea of how the velocity of light may be determined. Best done by visiting a project undertaken by some senior pupils, the topic may alternatively be dealt with by showing a film.

The topic of colour is a complex one and is not crucial to the development of our chosen themes. It is such an attractive one however, that it would be a pity if pupils could not dabble with it for a short while. Experiments 7.16, 7.17 and 7.18 would start off rudimentary ideas and perhaps the remainder, 7.19–7.27, could be dealt with as homework or club projects (perhaps in consort with the art department). Again, if personal interests can be caught, photography, the eye and optical illusions could be the subjects of pupil lecturettes as per Chapter 5.

Experimental Work

Demonstration 7.1.

(a) With the tube full of air it would take very large voltages to cause 'breakdown' ionisation of the gases. As the tube is evacuated however, electrons can be accelerated by a suitable voltage to energies sufficient to cause ionisation of the remaining gases in a manner suggested by the discussion on pp. 92–3 (see note on question 15, Ch. 2). This type of argument helps to explain the regions of dark and glowing gas visible in the tube at various stages of vacuum.

With an ordinary rotary (or 'backing') pump, it is usually possible to demonstrate a region of 'dark space' near the cathode, together with a reddish glow further along the tube; often, with further pumping this glow will later break up into 'striations', bands of alternate dark and glow (the above type of explanation still applies in successive stages). To get beyond the stage of striations and increased 'dark space' (not necessary at this juncture) it is probably necessary to use a diffusion pump as well and the rudiments of high vacuum technology—an exercise more suitable for a sixth year student.

(b) According to the tubes available in school, so the various

colours typical of the various gases can be demonstrated. (Examples of spectral lines for different gases are shown in *P.I.F.* Book Four.) The attention of pupils can then be directed towards local street (see note to question 16, Ch. 2) and advertisement lighting and asked, as a homework exercise, to comment on the possible gases used in the tubes. (This may not always be entirely fair unless the possibilities of mixture of gases and/or the use of coloured glass tube is allowed for.)

Demonstration 7.2. (a) The Nuffield smoke box (N.93), rectangular glass tanks or long glass tubes (at least 5 cm diameter) may also be used instead. For clarity, a fairly sharply defined beam is necessary, i.e. edge of 'projection window' should be well clear of the edge of the box.

With enough (not too much) smoke, the edges of the beam are clearly visible, and, on a macroscopic viewing are clearly straight when compared with a ruler or other straight edge.

(b) As the smoke is removed pupils can be given a good (oral) test of observation by being invited to note silently (mentally) all the changes taking place. On checking after all the smoke has been removed they should have at least noticed (i) the beam has 'disappeared', (ii) the hand or paper placed beyond the box is now more brightly illuminated (the beam is still passing through the box), (iii) the corners inside the box now appear to be much darker.

If more smoke is now slowly let into the box the above points can be rechecked by converse phenomena.

The explanation of all these phenomena is given by the sentence earlier in the text 'Most of the light which enters our eyes is, however, reflected'—first from the smoke particles which lie in the path of the beam; they scatter light to the corners of the box and to our eyes enabling us to see the beam. When these particles are removed we can no longer 'see' the beam, the corners of the box no longer receive this scattered light and, with this reduction in scattering, more light falls on the distant hand or paper.

Experiment 7.3. The shape and size of the shadow follow very closely that of the hand—if placed near enough to the paper to avoid unduly distracting penumbra effects from other reflected (scattered) light. This suggests that the sun's rays are very nearly parallel.

Experiment 7.4. Pinhole cameras are most easily and cheaply made at home as suggested in the text, but are available commercially (N.91). Teachers should take care that this work, so familiar to them, is not allowed to take up too much time in exploring all the possible uses and developments of the pinhole camera, bearing in mind the general aims of this *whole* chapter on light and the *whole*

pattern of work on waves. The object here is for pupils, with their own pinhole cameras, to find examples of the straight line propagation of light, in this case by observing the sharp, inverted image formed on the screen by a single, small pinhole. That is the important 'message' of this experiment.

Having found that however there is no reason why a few extra minutes may not be spent by each pupil puncturing first another 2 or 3 small holes and then punching a few more near-by until they overlap to form a larger hole. In each case they should notice the effect on the image—and leave it at that. There is no need to make a series of formal class 'experiments' with many ray diagrams and notes to record all of these effects.

Experiment 7.5. Here again work familiar to teachers can be speeded up by providing pupils with a cyclostyled sheet of paper with partially completed notes, e.g. a selection of angles of incidence printed (0° , 10° , 20° , etc.) with blank spaces for the corresponding angles of reflection—and some blank spaces for a pupil's choices of angles of incidence too!

Model 7.6. Fig. 210 and the subsequent text indicate what is expected and also indicate that the surface should be sufficiently rough to scatter the table tennis balls. Pupils can be asked to provide their own ideas of a 'rough surface'. If beaten by this task however, a sprinkling of small stones on a tray should be sufficient.

Demonstration 7.7.

(a) Again this affords an opportunity for the exercise of real observation. For small angles of incidence, those 'knowing the answer' will expect to see the incident ray and the emergent refracted ray. Any pupils noticing only these should be criticised and told to look again—for the weaker reflected ray. With care, as the angle of incidence is increased, variations in relative intensity can be detected before the total internal reflection occurs.

(b) Semicircular 'Perspex' or glass blocks will possibly show the variations in relative intensity of the three rays more clearly. If there are sufficient to give each pair of pupils a block and raybox, it may again be advantageous to provide them with a cyclostyled paper with the position of the block drawn in, together with a few lines drawn to show *some* suggested paths of incident rays and also a semi-completed table of results for rapid recording.

Experiment 7.8. This simply performed experiment is another example of total internal reflection taking place at the water/air surface around the egg.

Experiment 7.9. (a) Although this can be performed solo, it is probably better done in pairs enabling the observer to keep her eye steady. The partner slowly and carefully pouring in the water will then enable the observer to see the coin come gradually into view as the refracted rays 'clear the edge' of the can.

(b) Encourage pupils to view the pencil from various positions—directly above, above but at an angle, from the sides, etc. If pupils only look from one position they may by chance strike one from which they see nothing extraordinary.

Experiment 7.10. Teachers should resist any temptation to 'verify Snell's law' at this point. All that is required is that pupils should notice the bending of light rays by varying amounts (depending on the angle of incidence, and the sense depending on the change in media) the emergent ray parallel to but displaced from the path of the incident ray and possibly effects of total internal reflection with the parallel-sided block.

With the triangular prism again all that is 'expected' is the successive bending effects on entering and leaving the glass. If however a more observant pupil does notice total internal reflection effects or colouring effects (dispersion) he should be congratulated and—if there is time—encouraged to follow this up himself (see Experiment 7.16 *et seq.*).

Demonstration 7.11. A description of the images as sharp or fuzzy may become a matter of opinion if hardboard with a different size of hole is used; if the holes are small enough and the relative distances large enough sharp images should be obtained. This is of course a recapitulation of some of the 'extra' points mentioned in Experiment 7.4.

Experiment 7.12.

(a) The selection of lenses should include convex ones of various focal lengths and a few concave ones as extra puzzles. The point is to encourage pupils to handle these and see for themselves what various lenses can and cannot do, e.g. (without actually using these terms at this stage) formation of real and virtual images, closer to or further from the various lenses.

Probably this is all that time will allow of with a given class. Nevertheless, one should be on the look-out for pupils who show a particular interest in these lenses and one could follow up with a series of open experiments—possibly conducted at home with borrowed lenses—of using these in pairs and various combinations, perhaps even leading to someone making a simple telescope or microscope as a little project.

While follow-up ideas such as these may be interesting, they should

NOT be developed into a series of formal lessons on the telescope, etc., nor allowed to take up class time to the detriment of the overall study of waves.

(b) Experimenting with a thin wire and a very small loop should enable one to see (for example) print in a newspaper considerably magnified.

Demonstration 7.13. To say 'the rod and the liquid have the same refractive index' is probably meaningless to the pupil. One might explain this by pointing out that a transparent rod is normally visible in a liquid because one sees through it something which is 'out of place' against the background viewed through the liquid. This is due to the refraction between the liquid and the rod. In the case quoted, the 'Pyrex' rod is invisible because there is no refraction between it and the liquid and therefore the background is all 'in place'.

Oleic acid and a 'Pyrex' rod or glass tube give similar results.

Experiment 7.14. Until this experiment is performed, pupils could offer explanations of the earlier experiments in terms of particles of light travelling along the rays. This experiment—especially when related to ripple tank and other wave analogies—illustrates that visible light can indeed be considered to have wave properties. The experiment is virtually a repeat of Experiment 4.20, this time showing in addition a greater spacing between the red bands than the blue.

Experiment 7.15. It is important to stress that the Newton ring pattern should be looked for by *reflection* and not transmission through the plates. Microscope slides may be used.

Experiment 7.16. This standard experiment should present no difficulties in producing the spectral colours (red, orange, yellow, green, blue, violet) from white light. Excellent diffraction grating (replica) material is available from Proops (now Sound and Science Ltd., 3-5 Eden Grove, Holloway, London N.7.).

Demonstration 7.17. Care should be taken to ensure that the liquid Lux and aluminium powder is fairly evenly distributed in the bulk of water.

Experiment 7.18. Again, a thin but even sprinkling of the beads produces best results. Beware of fingers which find these fascinating beads irresistible!

Experiment 7.19.

(a) A prior try out is advisable to find a pair of matched prisms

which will in fact restore the white light in an acceptable manner.

(b) Similarly a little care and practice may be needed before demonstrating this successfully.

Experiment 7.20.

(a) If the original position of the screen at X is marked on the bench, it will assist matters when the slit is substituted and its position across the spectrum adjusted. The slit should be wide enough to allow through adequate light; it should not be too wide however or else selection of merely one colour will be difficult.

(b) and (c) These illustrate the action of filters, discussed later in the text.

Experiment 7.21. As an alternative to one box and two mirrors, one can make three boxes—one for each primary colour. Because the various filters reduce the intensity of light by various amounts the distances of the coloured light sources will have to be adjusted—probably blue closest, then green, then red—to obtain a reasonably ‘balanced’ white light.

Three filters superimposed should prevent all the light from passing.

Experiment 7.22. Pupils could be encouraged to perform similar experiments with filters of their own making, e.g. sweet wrappers, tinted transparent plastics, etc.

Demonstration 7.23. These sources produce line spectra. The tungsten lamp produces a continuous spectrum. Direct reading portable spectrometers are commercially available or can be made. A cardboard tube with a narrow slit at one end and a piece of diffraction grating (Proops) at the other, makes a cheap and effective spectroscope. Dimensions are not critical—3 cm diameter and 30 cm long are typical. The inside of the tube should be matt black.

Demonstration 7.24. If a mercury vapour lamp is available, an alternative method avoiding the use of spectrometer, is to shine the light from the mercury vapour lamp onto a (Day-glo) screen. If a plastic bottle of mercury is held between the lamp and the screen and given a sharp, gentle squeeze the emanation of mercury vapour is clearly seen by its (absorption) shadow cast on the screen—an indication of just how much dangerous mercury vapour there can be from mercury carelessly left exposed in some laboratories.

Demonstration 7.25. The red cross is seen as the complementary colour to the background. Our past experience seems to encourage us to see the background as ‘white’ so that the ‘real white’ of the

'red' cross is seen as the complement. This is a really staggering demonstration!

For a full discussion of this type of work see Dr. E. H. Land's 'Experiments in Colour Vision', *Scientific American* reprint, May 1959.

Experiment 7.26. Complementary colours are usually seen against a white wall or paper, believed to be due to 'fatigue' of the particular detectors in one's eye to the particular colour to which they are exposed; they then exhibit a kind of 'reaction'.

Experiment 7.27. It is to be expected that some pupils will find this easier to do than others. It is more effective if pupils are told to keep their arms *bent*—if they are stretched it is comparatively easy to make the pencils meet.

ANSWERS TO QUESTIONS

1. Answers to this should be in terms of the discussion on pp. 92–3.
2. The atom must be excited—as per above.
3. Visible light, ultra-violet and infra-red rays are most readily detected. With suitable detectors, the range can be extended to include the frequency bands of radio and soft X rays. Extra-terrestrial rays are more likely to have come from other parts of the cosmos than our own Sun.
4. Since the main purpose of such lamps is to generate light, any energy which is used to produce heat, rather than light, is 'wasted'—leading to a lower 'efficiency'.
5. In the heavens, the only illuminated sources of light a pupil is likely to see are the moon, a planet or a satellite—anything else, a star, sun or comet is a luminous source. Most things he will see about him on earth will be illuminated.
6.
 - (a) Illuminated.
 - (b) A TV screen will be illuminated when not switched on, but when it is, a glowing picture on the screen will act as a luminous source of light.
 - (c) Luminous.
7. Yes.
8. Glass, water, a cloud, etc.
9. Theoretically, a point should have no magnitude; in reality, if it is to emit appreciable light at all, a point source must have a finite size. The arbitrary description 'point' or 'extended' source is really a relative matter depending not only on the size of the source itself but its distance from objects, detectors, etc., e.g. a luminous

star whose size may be many times larger than the Earth may, for some purposes, be considered a point source by a terrestrial observer because of its great distance.

10. Light travels in straight lines.

11. For the purposes of this work, 'umbra' means complete shadow, 'penumbra' means partial shadow.

12. See Fig. 31.

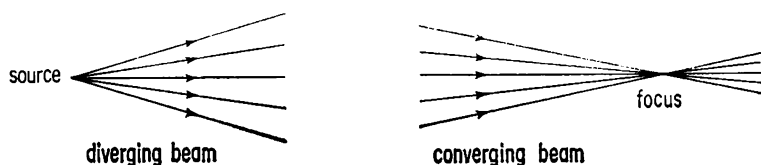


FIG. 31

13. See Fig. 32.

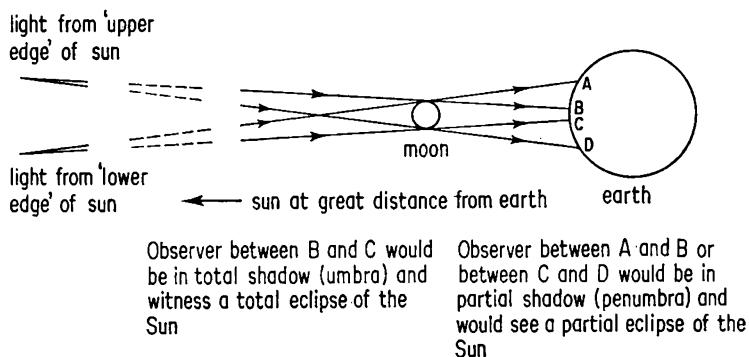


FIG. 32

14. There would be no penumbra and only a sharply defined umbra.

15. One that does not transmit light and only absorbs a minimum amount. For visible light, polished metal.

16. From the information given here the velocity of light can be shown to be 186,560 miles per second.

The time for 1 complete revolution of the 8-sided mirror = $\frac{1}{530}$ s
thus

the time for $\frac{1}{8}$ complete revolution of the 8 sided mirror = $\frac{1}{530 \times 8}$ s

This is the time it takes for face 2 to 'replace' face 3 exactly, enabling the observer to again see the light. During this time the light has travelled 44 miles.

Hence the velocity of light = $44 / \frac{1}{530 \times 8} = 44 \times 530 \times 8$ miles per second.

17. Yes, at higher multiples of 530 which for example enable face 1 to 'replace' face 3 correctly, viz. 1060 c/s, etc.

18. Refraction.

19. Red.

20. Violet.

21. From the upper drop an observer receives red light (the violet passing overhead); from the lower drop the observer receives violet light (the red passing below). Therefore, although for light received from any *one* drop, red is below violet, an observer receiving light from many different drops sees red above violet.

22. See *P.I.F.*, Book One, p. 36, for examples.

8 Infra-red Radiation (pp. 110–115)

The reader is asked to refer to Chapter 6 on p. 106 before beginning this chapter.

Experimental Work

Experiment 8.1. With rising temperature of the filament, a greater intensity of infra-red radiation (probably more energetic too) gives a larger meter reading.

Experiment 8.2. The slit width here is very much greater than the wavelength of the infra-red radiation so that diffraction effects are small. There is little evidence of any infra-red radiation in the 'shadow', i.e. the rays travel in straight lines.

Experiment 8.3.

(a) As in Demonstration 6.3 (c) the radiation is reflected best by a polished metal surface; the angle of incidence is equal to the angle of reflection.

(b) A stronger signal is received from the focussed rays. Practical examples could include the structure of curved reflectors on electric fires, infra-red lamps, infra-red grills and solar furnaces.

Experiment 8.4. The highest reading is registered beyond the red end of the spectrum. Beware filling the prism designed for use with paraffin with carbon disulphide as this may dissolve the cement used in its construction.

Demonstration 8.5. This is a striking example of the focussing of infra-red rays by a 'lens' action. When the detector is placed in front of the flask, in the direct path of the beam, a fairly low meter reading is obtained. When, however, the detector is placed at the focus, a marked increase in meter reading is noticed. If the source is not too distant from the flask and if the focus has been found by the detector, substitution of one's hand for the detector will give a very real tactile confirmation of the focused 'hot spot'.

Experiment 8.6. The glass, though transparent to visible light is opaque to infra-red wavelengths.

Experiment 8.7. After reducing heat losses by other means—with the various corks—greater radiation losses from the blackened

calorimeter will lead to a more rapid drop in temperature in it than in the shiny one.

Experiment 8.8. Here, demonstrated again, the blackened can is not only a better radiator but also a better absorber.

ANSWERS TO QUESTIONS

1. Disadvantages include the element of possible danger, limited sensitivity and inability to take quantitative readings.

2. Careful—could be made a catch question! If the entire system of the two metals were heated (i.e. both junctions), apart from the barely detectable contact potential, the answer would be 'nothing'. What is implied, however, is if one junction were heated an appreciable electric potential difference would be set up (current would flow).

3. We would have a thermocouple.

4. The radiation is absorbed by the matt black surface, the air inside the flask is warmed and expands. This effect is made visible by a change in level of the coloured liquid in the tube. In (a) it would move down and in (b) it would move down in the left and up in the right limb of the tube.

5. They travel at the same speed.

6. They both travel in straight lines and are absorbed or reflected by a cloud which is effectively nearly opaque to them.

7. It is generally an advantage to reduce heat losses from the surfaces of these containers.

8. In the case of kettles and saucepans it means that less heat (cost) is then required to boil a given amount of water (for example), while for the vacuum flask its whole point is to reduce any heat loss if a hot drink is to be kept hot. A polished surface will also reduce heat absorption in a flask used to keep something cold.

9. The brighter snow reflects the sun's radiation; the darker leaf absorbs the radiation, warms up and thereby melts the snow beneath it, thus gradually sinking into the snow.

10. Some schools will have one, in others the local museum may be appropriate. Radiation is reflected by the shiny side of the vanes but absorbed by the dark side which then warms slightly. Molecules of air striking the shiny side of the vanes are reflected, leaving the surface with nearly the same energy with which they arrived; those striking the dark side, however, leave with greater energy. By Newton's third law, since they leave the (dark) vane surface with greater velocity so the vane must leave the molecules with greater velocity, i.e. the vane moves 'forward', bright side leading, and the paddles begin to revolve around their axis.

Radiometers are available from Proops.

9 Electron Pumps (pp. 116–119)

Introduction

Demonstration 9.1 is designed to remind pupils of something they discovered in Chapters 1, 2 and 3: that flow of fluid, of heat and of electric charge are due to a difference of pressure, of temperature and of potential, respectively.

The three experiments which follow illustrate several methods, which may not have been investigated previously, of producing a current.

Experimental Work

Demonstration 9.1. (a) The water stops flowing when there is no pressure difference between the ends of the tube, i.e. when the water levels are equal, as then there is the same head of water above each end of the tube.

(b) The flow stops when there is no pressure difference between the ends of the tube.

(c) Heat flow stops when there is no temperature difference between the ends.

(d) Charge stops flowing when there is no potential difference between the ends of the connecting wire, i.e. the electroscopes are at the same potential. Unless they have the same capacity, they do not have the same charge when flow stops.

If the charged electroscope initially had a positive charge, electrons would flow to it from the uncharged electroscope until the potentials were equal.

Experiment 9.2.

(a) A milliammeter (moving coil).

(b) No comment required.

Experiment 9.3. Suitable cheap microphone inserts can be obtained from Land, Speight & Co. Ltd., 49 St. Vincent Crescent, Glasgow.

Philip Harris now supply a very simple but impressive device which produces a 5 mm spark as a result of piez o-electric pressure.

Demonstration 9.4. Charge flows from the high potential sphere of the generator to the pupil, so that his hairs acquire like charges. These cause each hair to repel the others round about it. When the

charged boy touches one terminal of the micro-ammeter, connected as shown, electrons flow from earth to neutralise the positive charge on him and the meter registers their passage.

ANSWERS TO QUESTIONS

1. 'Interference' is the most satisfactory answer, as has been emphasised in Chapter 7.

2. Metals and to a lesser extent carbon (graphite). Refer back to results of 2.7 (*b*) and 2.37 (*a*) and (*b*).

3. See Chapter 2. Suggestions might include the use of

- (i) a cell or battery,
- (ii) a thermocouple,
- (iii) a dynamo,
- (iv) a Van de Graaff generator, and
- (v) a charged polythene rod.

4. Negative ions move to the anode and positive ions to the cathode. At the electrodes, the ions either accept or donate electrons and become electrically neutral. Deposition of a solid element, release of a gaseous element or chemical reaction with the resulting formation of a compound, may follow.

5. See text. Other answers might include various industrial preparations, e.g. of sodium, chlorine, aluminium, potassium and magnesium, purification of copper, lead, manganese, zinc and iron, anodising.

6. The filament or element becomes hot, sufficiently hot to give off a little light in the case of the element and much light in the case of the filament.

7. The iron becomes magnetised. Direct current would normally be used. See note on Demonstration 14.4.

8. In shop, cinema and theatre signs and in house strip lighting.

10 A Vicious Circle (pp. 120–127)

Introduction

A reminder about conductors and insulators, plus the additional information that a substance may be a good insulator under some conditions and a good conductor under others, is provided by Demonstration 10.1.

Experiment 10.2 deals with the variation in current due to change in resistance, and Experiment 10.3 with the variation in current due to change in potential difference, the measurements in the latter leading to the discovery of Ohm's law.

The effect on current in a circuit of connecting resistors in series and in parallel is studied in Experiment 10.4.

The body as a conductor and the effect of reducing contact resistance at the fingers are investigated in Experiment 10.5.

Experiment 10.6 is lengthy but important. Pupils should learn much from it about the effect of connecting cells and resistors in series and in parallel, and about switching.

The function of a fuse is introduced in Experiment 10.7.

Experiments 10.8 and 10.9 lead to the conclusion that the energy consumed by a device such as a light bulb depends on the current passed through it, which in turn depends on the potential difference across it; the importance of power follows.

Experimental Work

Demonstration 10.1. Warning! As mains voltage is being applied to bare wires, strict care must be taken; *Pupils should ON NO ACCOUNT be allowed to carry out the experiment.*

After the glass has been heated gently for a short time, the bulb begins to glow. Glass does conduct before it reaches its melting point, but it is sometimes difficult to establish this by the glowing of the bulb, the sag of the glass as it melts coinciding with the appearance of light from the bulb. After the Bunsen has been removed, the bulb continues glowing for some time, the glass being heated by the current through it.

Experiment 10.2. When the resistance is increased, the bulb becomes less bright, i.e. the current becomes less. Reversing the direction of the current makes no difference.

Experiment 10.3.—an opportunity for pupils to discover for themselves an important relationship.

When the second cell is added, it is assumed that its e.m.f. is the same as that of the first cell. The graph obtained should be a straight line passing through the origin. As the internal resistance of each cell is very much less than that of the resistor, the change in resistance caused by the introduction of successive cells will not 'spoil' the results.

The calculated values of V/I should be approximately equal, i.e. the current in the circuit is directly proportional to the total p.d. in the circuit. The average value of V/I is the resistance of the circuit, in this case approximately $6\text{ k}\Omega$ plus the resistance of the meter.

As the current is very small, heating and therefore change in resistance is negligible.

Experiment 10.4.

(a) As resistances other than the two $6\text{ k}\Omega$ resistors are negligible, the addition of the second $6\text{ k}\Omega$ resistor will half the current. The meter reading in mA, dividing by 1,000 to bring it to amps and this then divided into 3 volts gives the total resistance.

(b) Connecting the second $6\text{ k}\Omega$ resistor in parallel with the first doubles the current; the resistance has been halved. Thus the total resistance of two equal resistors in parallel is half the resistance of one of them.

The formula $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$ is NOT required at this stage.

Experiment 10.5. Typical meter readings are $2\text{ }\mu\text{A}$ when the fingers are dry and $40\text{ }\mu\text{A}$ when they are wet, indicating that the resistance of the body is greatly reduced by reducing the surface resistance. The surface therefore contains the greater part of the body's resistance.

It should be noted that surface resistance is not due to the skin only but also to the air trapped between the skin and the wire when the latter is gripped. When the fingers are wet this air is replaced by water, which has a much lower resistance.

Experiment 10.6. The circuits are as shown in Fig. 33.

Short circuiting a cell will very quickly exhaust it. Short circuiting an accumulator causes overheating and consequent buckling of the plates.

Experiment 10.7. As the current increases the heat generated in the fuse wire increases and its temperature rises. The fuse is unlikely to melt when 5 A passes through it; the current at which such a fuse

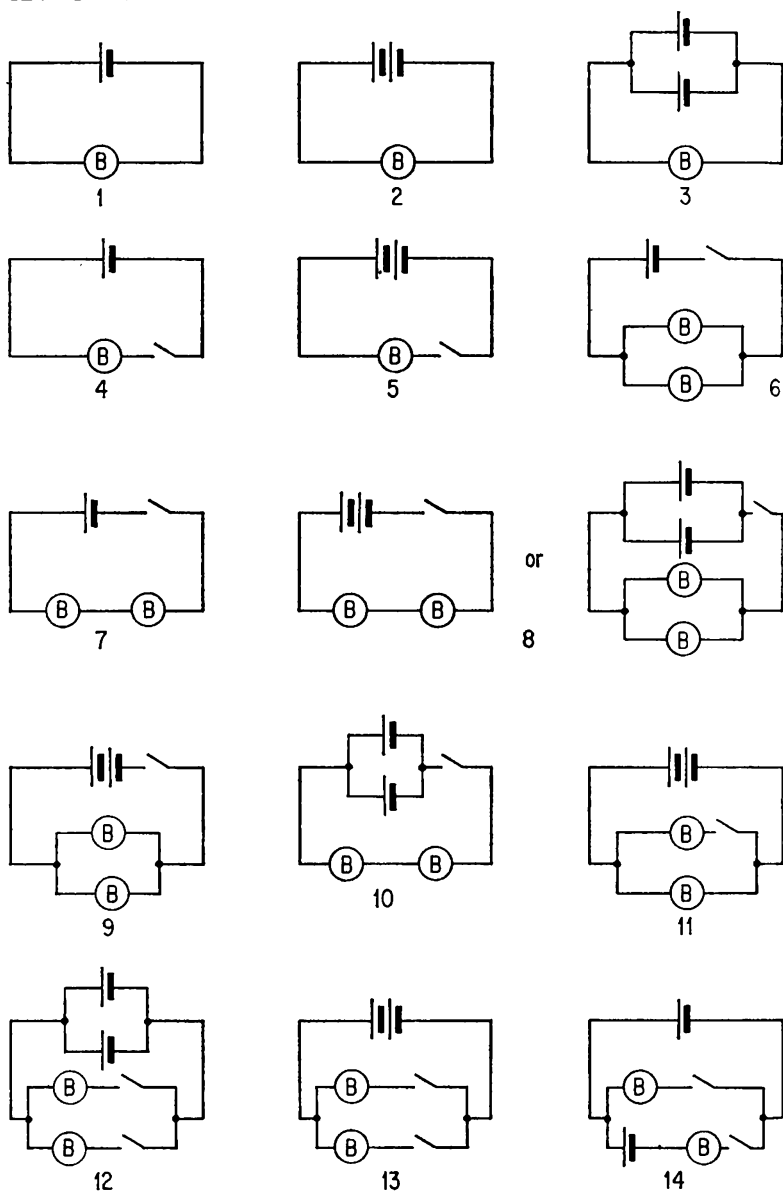


FIG. 33

melts often approaches twice this value, to allow for any initial surge of current.

If fuses were not used in mains circuits, a fault in a device being used might lead to a greatly excessive current being passed through

the device itself and through the house wiring. This might cause further damage to the device and overheating the wiring might cause a fire. Alternatively a fault in the house wiring could lead to a short circuit, a high current, overheating and a fire.

In testing a $\frac{1}{4}$ amp fuse, a 0–1 A meter and a rheostat capable of reducing the initial current to a value less than $\frac{1}{4}$ amp, e.g. 0–10 Ω , should be used.

Demonstration 10.8. As the voltage is increased, the ammeter indicates that the current is increasing; it must be the same in each bulb. The larger bulb glows first and is always the brighter (here and in the next experiment, 'brightness' is used to indicate a qualitative assessment of the amount of light being emitted).

On the assumption that the resistance of the ammeter is negligible (it may not be) and therefore the p.d. across it is negligible, the p.d. across the mains bulb would be 237.5 V.

Remember that, unless precautions such as the placing of an isolating transformer between it and the mains input have been taken, the variable transformer will have one output wire live, even when it is set to give zero output voltage, and take care accordingly.

Experiment 10.9. The bulbs are in parallel and so the voltage across them is always the same. The 24 W lamp is always brighter than the other (0.24 W), as it takes a much higher current. If the current through the rheostat were 4 amp and the current through the small bulb were 0.04 amp, then 3.96 amp would pass through the large bulb, assuming the current through the voltmeter to be negligible.

Any pair of bulbs of widely differing power rating but designed to operate at the same voltage are suitable. The mains could be used, with variable transformer and, e.g. 40 W and 200 W bulbs.

ANSWERS TO QUESTIONS

1. The resistance becomes greater.
2. Density.

$$3. \text{ Resistance of bulb} = \frac{V}{I} = \frac{3.5}{0.3} = 11.7 \Omega$$

4. The voltage is so high that the p.d. across your body when one part touches the mains and another part is earthed is enough to drive a large current through your body and give you a serious shock. The mains have a high current capacity, unlike for example, a Van de Graaff generator which, although it can provide a p.d. of thousands of volts across your body, can deliver a very small current only and so is not dangerous.

5. The resistance of the body is reduced and so a greater current will flow.

$$6. \text{ Resistance} = \frac{V}{I} = \frac{1.5}{0.00015} = 10^4 \Omega$$

7. 3 V, 1.5 V and 0 V respectively.

8. The greater p.d. between the ends of the battery leads to a higher current through the circuit.

This is particularly effective when the external resistance is very much greater than the internal resistance, for then the increase in the internal resistance brought about by the increase in the number of cells has little effect on the total resistance of the circuit. When the external resistance is much less than the cell resistance, the increase in current produced by forming the battery is very small.

9. When in parallel, the total current obtained is shared by the cells. This reduces the current supplied by each cell and extends the life of the cell.

10. (See Fig. 34.)

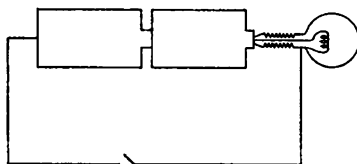


FIG. 34

11. (See Fig. 35.)

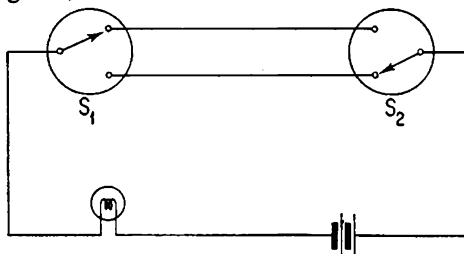


FIG. 35

If either switch is moved, the circuit is completed. Thereafter, moving either switch breaks the circuit.

12. Zero.

13. 3 amps on A, B and E; zero on D.

14. 6 amps on A and E; 4 amps on D.

15. (i) All meter readings would decrease.

(ii) If R_s were reduced, the total resistance of the circuit would be reduced and so the total current increased; the readings on A, B and E would increase. The reading on D would also increase, but the reading on C would decrease.

Consider R_3 being gradually reduced to zero. Eventually almost all the current will flow through D and practically none through C. This assumes resistance of C and D to be negligible.

16. It has been changed into heat energy.

17. No.

18. Whereas the distribution of heat could perhaps be improved, all the electrical energy used is turned into heat (in a convector, heat energy is the only type produced in the first place, and in others such as fan and radiant heaters, the sound and light produced is eventually turned into heat).

19. Typical values are: bulb 100 W, iron 750 W, one bar radiator 1000 W, immersion heater 3000 W, refrigerator 100 W, door bell 2 W

20. About 1 watt (a 2.5 V 0.3 A bulb has a power of 0.75 W).

21. $1 \text{ kWh} = 36 \times 10^5 \text{ watt seconds} = 36 \times 10^6 \text{ joules.}$

22. Energy used $= 0.1 \times 100 = 10 \text{ kWh. Cost} = 10 \times 2\text{d.} = 1\text{s. } 8\text{d.}$

23. Energy used $= 3 \times 100 = 300 \text{ kWh. Cost} = 300 \times 2\text{d.} = 600\text{d.} = \text{£}2. 10\text{s.}$

24. Bulb: Current $= \frac{W}{V} = \frac{100}{250} = 0.4 \text{ A}$

Heater: Current $= \frac{W}{V} = \frac{3000}{250} = 12 \text{ A}$

25. Energy used in one hour $= VI t = \frac{2.5 \times 0.3 \times 1}{1000} = 0.00075 \text{ kWh}$

$\therefore 0.75 \text{ kWh costs } 6000\text{d.}$

$\therefore 1 \text{ kWh costs } 8000\text{d.} = \text{£}33. 6\text{s. } 8\text{d.}$

26. If energy costs 2d. per unit instead of £33. 6s. 8d. per unit, the bulb could be lit for 4000 times as long for the same cost. Therefore the answer is 4000 hours.

27-28.

<i>Rating in Watts</i>	<i>Current in amps</i>	<i>Suggested fuse in amps</i>
60	0.24	1
100	0.4	1
300	1.2	2
600	2.4	5
1000	4.0	5
1500	6.0	13
2500	10.0	13

11 Cells (pp. 128–132)

Introduction

Ammeters and voltmeters are considered to be essential pieces of apparatus in the study of cells and hence Experiment 11.1 and Demonstration 11.2 deal briefly with a simple ammeter and a simple voltmeter respectively. The more obvious purpose of Experiment 11.1 is to build a voltaic pile. As suggested in the text, this experiment could well be done at home.

In Experiment 11.3, various metals are investigated with a view to finding which pair is most suitable for the electrodes of a cell. A rather unusual cell, using a pair of these metals, is built in Experiment 11.4.

The simple cell and polarisation and its prevention are studied in Experiment 11.5, while a quick look at other practical cells follows in Experiment 11.6. The construction of a secondary cell, in this case a lead accumulator, is shown in Demonstration 11.7.

Experimental Work

Experiment 11.1. The galvanometer is named after Galvani.

The former should be just big enough to allow the compass inside it.

Demonstration 11.2. The leaves diverge as the voltage is increased, but full-scale deflection, which will vary with different types of electroscope, corresponds to hundreds of volts. Thus the electroscope could be used as a voltmeter, but its sensitivity would be very low; it would not be suitable for measuring low voltages. Its accuracy would also be low.

Experiment 11.3. Good contact between the carbon block and the wire connecting it to the voltmeter can be obtained by putting a drop of mercury on top of the block and holding the end of the wire in it. Care should be taken lest pupils think that the mercury plays any part in the chemical action; if they are not convinced that it does not, mechanical connection should be made.

When tap water is used in place of copper sulphate, all readings are slightly smaller.

Experiment 11.4. No comment needed.

Experiment 11.5.

(a) When the bulb is inserted, the reading on the voltmeter drops sharply (in a typical trial from 0.7 V to practically zero when a 1.5 V, 0.2 A bulb is used).

(b) The bulb lights, but fairly quickly becomes dimmer. The voltage drops, but by a relatively small amount. The addition of dichromate causes the bulb to relight (text, p. 131). The voltage remains fairly steady for some time at a value not much less than that when the bulb was not in position.

Bringing the plates closer together decreases the internal resistance of the cell. When the bulb is not in position, this makes very little difference in the total resistance of the circuit, the voltmeter resistance being high. The increase in current is very small and the resulting increase in the voltmeter reading is unlikely to be obvious. When the bulb is in position, the fractional change in resistance is much greater and an increase in the voltmeter reading should be easily detected.

Reducing the area of the plates increases the internal resistance of the cell. By similar reasoning to the above, the voltmeter reading will become less, the decrease being more obvious when the bulb is in position.

Experiment 11.6. Assuming that an ordinary current operated voltmeter is used, the reading on it is the p.d. outside the cell rather than its e.m.f., but the resistance inside the cell is normally very much less than the resistance outside it and therefore the p.d. inside the cell is very small. In this case the voltmeter reading is a reliable indication of the e.m.f. With a Weston standard cell, an additional high resistance has to be put into the circuit.

The e.m.f. of a large dry cell is the same as that of a small one, but a large cell has a much smaller internal resistance and can therefore deliver much larger currents. Differences in age and history may produce confusing results.

The source of energy of a dry cell is the chemicals it contains and therefore a large cell, containing more, has a longer life.

Demonstration 11.7. In the first instance the bulb does not light. There is no current flowing; using an ammeter in place of the bulb will convince the cynics.

After the cell has been charged by passing current through it, it lights the bulb. The energy used in charging the cell (forming lead dioxide on the anode and strengthening the acid) is stored for future use.

The process of discharging and again recharging can be continued

over, say, two visits of the class to the lab, emphasising the energy conversion process.

ANSWERS TO QUESTIONS

- 1. Copper and carbon.**
- 2. Magnesium and zinc.**

12 Magnetic Magic (pp. 133–138)

Introduction

Forces between currents are investigated in Demonstrations 12.1–12.4. There is no need to do all of them; 12.1 (b), 12.2 and 12.4 are the simplest and are also among the most instructive, as repulsion as well as attraction can be shown.

In Demonstration 12.4, the results of the previous experiments are used to produce continuous rotation and thus to introduce the electric motor (studied in more detail in Ch. 14).

The suggestion that the force between currents may be of the same nature as the force between magnets is tested in Experiments 12.6 and 12.7. The latter provides more information than the former and is less likely to lead to buckled accumulator plates!

Having established that a current has a magnetic field associated with it, the form of this field in the case of a straight conductor is found in Experiment 12.8.

Experimental Work

Demonstration 12.1.

(a) When the currents are in the same direction, the pivoted wire is attracted towards the other.

(ii) When the currents are opposite, the pivoted wire is repelled. When the distance between the conductors is reduced, the force is increased, shown by the greater deflection of the pivoted wire. This should be investigated with the currents in opposite directions, otherwise attraction will eventually make the wires touch.

The force also depends on the current in the expected way: the smaller the current the smaller the force.

(b) When the currents in the halves of the tape are in opposite directions, repulsion leads to the halves being forced apart; when the currents are in the same direction, the halves move together.

In the latter case, if a piece of cardboard or light rod is slipped between the pieces of tape at the bottom, they are held apart so that the attraction when the current is switched on can be easily seen.

For this and many of the other experiments in the chapter, the Nuffield low voltage power unit (N.104) is useful.

Demonstration 12.2. The electron beam is deflected towards the aluminium tape when the current in the latter is in the same direction

as that in the tube, and away from the tape when the tape current is reversed.

Any tube in which the deflection of an electron beam can be seen, e.g. a Maltese cross tube, will do.

Demonstration 12.3. As the current in corresponding parts of adjacent turns of the coil is flowing in the same direction, each turn attracts its neighbours and the coil contracts, pulling the end out of the mercury. This breaks the circuit so that the coil expands, the end enters the mercury and the process is repeated.

Various gauges and materials can be used to make the coil but wire that is both thick and springy should be avoided. Copper of s.w.g. 20 or more is suitable. Several amps may be required.

Demonstration 12.4. When the currents are in the same directions, the coils attract each other; when the current in one coil is reversed, there is repulsion.

The effect is most easily seen when the lengths of suspending tape are long; at least 15 cm has been found to be satisfactory. Make sure the rheostat is capable of carrying the current required (4 amps will probably be enough) without acting as a radiator.

Demonstration 12.5. No comment is needed.

Experiment 12.6. When no current is flowing, the filings are unaffected by the copper wire; when current does flow the filings near the wire are disturbed and some adhere to the wire. When the current is switched off the magnetic effect disappears.

The current is maintained for a short time only to prevent damage to the accumulator.

Experiment 12.7.

(a) When the current is switched on the compass rotates, the angle depending on the size of the current and the distance between the compass and the wire.

(b) The compass rotates in the opposite direction.

(c) This reverses the current direction and so reverses the directions of rotation in (a) and (b).

Copper wire of 24 s.w.g. or less is suitable. It can carry the current required without excessive heating. There is no need to remove the insulation from it. With the circuit suggested the current will be about 4 amps and so the power rating of the resistor must be at least 8 W. A rheostat capable of taking at least 4 amps could be used, its resistance being decreased until the effect is produced.

The low voltage supply (N.104) is an ideal alternative.

Experiment 12.8. Before the current is switched on, the compasses point N—S. Unless they are very close together they will not have much effect on each other. When the current is switched on, they adopt a head to tail, N pole to S pole, attitude, reversing their direction when the current is reversed.

ANSWERS TO QUESTIONS

1. Consider Fig. 286 (Pupils' Book). When electrons flow through the wire from the girl's left to right hand the compass turns so that the N pole is towards her. If the compass were above the wire, the S pole would turn towards her. This confirms the rule.

13 Canned Currents (pp. 139–150)

Introduction

Domain theory of magnetism is approached by way of Experiments 13.1–13.3 and Demonstration 13.4. In Experiment 13.1 a magnet which can be sacrificed by cutting it up is made. In Experiment 13.2 this magnet is cut in half and each half found to be a magnet. The possibility of a magnet being made up of a large number of small magnets is investigated in Experiment 13.3. Indirect evidence, by means of the Barkhausen effect, for abrupt changes within a piece of iron as it is magnetised, is provided in Demonstration 13.4. Experiment 13.5, in which a knitting needle is demagnetised by raising it to a high temperature, completes the picture.

Experiments 13.6–13.9 are designed to investigate magnetic materials and forms of magnetism. To bring in diamagnetism may be unnecessary at this stage and so Experiment 13.7 could well be omitted. Experiments 13.8 and 13.9 both illustrate the Curie point and hence paramagnetism.

The existence of magnetic induction is shown by the results of Experiments 13.10 and 13.11, only one of which is essential.

Experiments 13.12 and 13.13 give information about magnetic fields, the latter by means of the traditional iron filings approach, and the former having merit because an effectively isolated pole actually moves along lines of force.

The position of the poles of a bar magnet can be found by Experiment 13.14. The setting of a suspended magnet follows in Experiment 13.15.

The study of declination and dip comes next, Experiment 3.16, on the former, being suitable for homework. Experiment 3.17 is a mechanical analogy designed to help pupils to understand about dip.

The effect of the Earth's magnetism on magnetic materials can be investigated in Experiments 13.18 and 13.19. The latter could be done at home.

Experimental Work

Experiment 13.1. When the N pole of the magnet is drawn towards X, then X becomes a S pole. To test, bring X up to the S pole of a compass; it should repel it.

Experiment 13.2. When the magnetised needle is halved, each half

is found to be a magnet. Thus the original poles can be separated from each other, but other poles appear so that the number of poles in each half of the needle is two. Isolated single poles cannot be produced.

Experiment 13.3. In the first instance the test tube of filings attracts both ends of the compass, i.e. it behaves like an unmagnetised piece of iron. After the magnet has been drawn along the tube as described, the test tube behaves like a magnet, the cork end repelling the S pole of a compass. After being shaken up, the tube is found to be unmagnetised.

See answers to questions (3) and (4).

Demonstration 13.4. To show that the hiss heard when the magnet is brought up to the coil is due to the rod, repeat with the rod absent; no hiss is heard. Therefore the rod is responsible for the hiss.

As, with the rod back in the coil, the hiss becomes quieter with successive thrusts of the magnet, it is reasonable to assume that the first thrust produced fairly big magnetic changes in the rod and successive thrusts merely added their contribution by producing changes in those parts of the rods which had not been affected by earlier thrusts. This becomes easier to explain once atomic magnets or domains have been introduced!

When the magnet (or the rod) is reversed, a relatively loud hiss is heard at first, diminishing with successive thrusts as the rod is remagnetised in the opposite direction.

The oscilloscope is most effective and is worth connecting in the circuit. A steel knitting needle can be used as the rod.

It is a common misconception among pupils who have seen this experiment that as atomic magnets turn or domain boundaries move, they make a noise!

Forewarned is forearmed!

The Unilab 300 mW audio amplifier loudspeaker unit is ideal for this experiment.

Experiment 13.5. After strong heating, the knitting needle is no longer a magnet. The atomic magnets have been disarranged as a result of the stronger molecular agitations produced by the heating.

Experiment 13.6. A fairly large selection, including such materials as iron, steel, cobalt, nickel, wood, paper, glass, polythene, compounds partly composed of magnetic elements, e.g. ferrous sulphate, and alloys such as those obtainable from the International Nickel Co. (reference 10 in the text), should be provided.

Any substance which can be picked up by a magnet will experience

a force of attraction, as will the magnet. Thus a compass needle, being a magnet, will be attracted by such a substance.

Experiment 13.7. (a) and (b) The bismuth turns so that its axis is at right angles to the magnetic field. Bismuth is diamagnetic.

Experiment 13.8. The Curie point for Jae metal is approximately 70°C . When the metal reaches this temperature it drops from the magnet. If the water is then allowed to cool, the metal can be picked up again when the temperature drops below the Curie point.

Experiment 13.9. When the temperature of the tack reaches the Curie point (about 770°C for iron), the tack is no longer ferromagnetic and drops off the tack above, taking the lower tacks with it.

Experiment 13.10. (a) When the bar magnet is brought up as shown, Y is attracted. This does not prove that Y is a S pole due to the influence of the magnet to which it is attached, as a nail hanging, e.g. by a thread, would behave in the same way. To show that Y is a S pole, the magnet in the hand must be reversed so that the S pole approaches Y; repulsion follows.

X is a N pole.

(b) Each is magnetised by induction, so that like poles are produced in the ends in contact with the magnet and in the lower ends also. The lower ends repel each other and, being free to move, separate, while the upper ends stay fairly close together, their distance apart depending on the strength of the magnet.

Experiment 13.11. If care is taken, a small separation between the magnet and the tacks should not lead to any tacks falling off the end of the chain. As the gap is increased the bottom tack falls off, then the next, etc.

Thus magnetic induction can take place both when the piece of iron or steel is in contact with and when it is near the magnet.

Tacks, being made of steel, retain some magnetism after an experiment such as this. It may not be enough to allow one tack to pick up another, but iron filings may be attracted or a compass needle repelled. It is advisable, before the experiment to make sure that the tacks used are not, at that time, magnets, and to make sure that the class knows that this is the case.

Experiment 13.12. The needle follows the lines of force of the bar magnet. Best results are obtained using a small cork and a small diameter tumbler or beaker in a large trough.

The needle can be magnetised by the method of Experiment 13.1.

An alternative arrangement is to place the magnet outside the trough.

Beware of surface tension effects: when the cork is near the tumbler or the sides of the trough it will move towards them.

Experiment 13.13. (a), (b) and (c) The field patterns found using compasses or filings are as in Fig. 36.

The compasses show the sense of the lines of force.

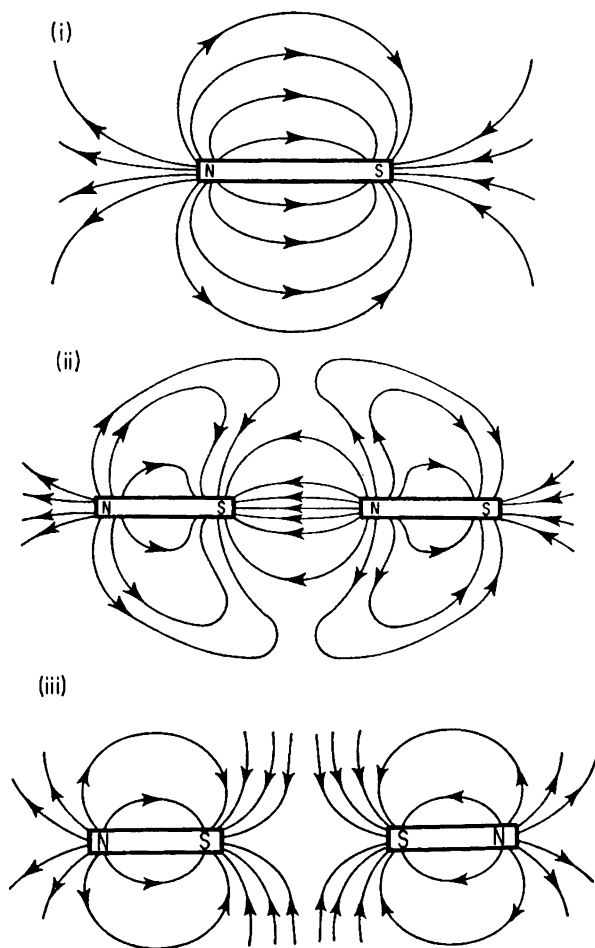


FIG. 36

There are very few filings, if any, in the middle of the cushion-shaped region in (iii), indicating the weakness of the field there. The resultant field is actually zero at this position, which is called a neutral point. The resultant force on an isolated pole at such a point is zero. A compass needle placed at a neutral point will not tend to set in any particular direction.

(d) In the case of a bar magnet with its N pole pointing north, the neutral points (two of them) lie on the line through the centre of the magnet at right angles to its axis. At these points, the field strengths of magnet and earth are equal and opposite.

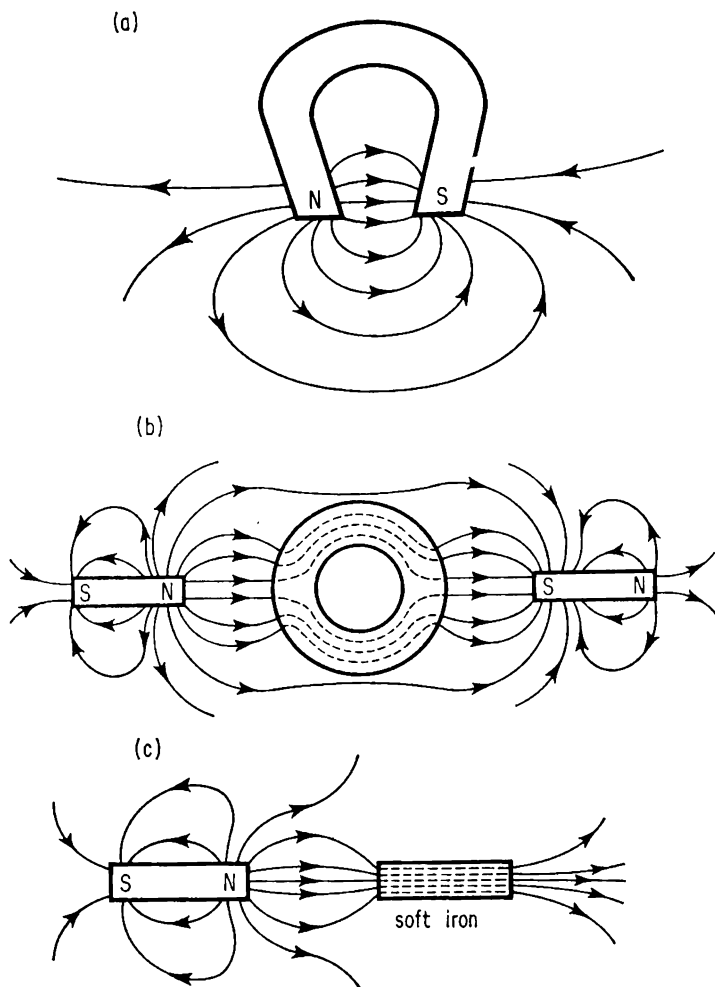


FIG. 37

When the N pole of the magnet faces South, the neutral points lie on the axis of the magnet produced.

In each case the position of the neutral points can be found using a compass.

(e) (See Fig. 37.)

The field inside the ring is zero.

Experiment 13.14. The strongest pull is indicated near the ends, i.e. at the poles, to which the field lines appear to converge.

Any reasonably strong bar magnet is satisfactory. It is convenient to hold the magnet flat on the bench while taking readings.

Experiment 13.15.

(a) No comment is needed.

(b) The two watch glasses should be placed edge to edge to form a double convex shape, or with convex sides in contact. A lens would perform the same function but is a bit more costly to replace if damaged.

Experiment 13.16. If British Summer Time is in effect, the sun will be at its highest point at one o'clock.

The experiment should be carried out at a place where there are no pieces of magnetic material to affect the compass.

May the sun shine for you!

Model 13.17. The point being illustrated is made clear on p. 149. Just as the compass needle is constrained to move in a horizontal plane and will do so under the influence of any magnetic force which has a horizontal component, so the trolley is constrained to move in a horizontal plane and will do so if a force having a horizontal component in the direction in which it can move is applied.

Experiment 13.18. The bottom of the strip turns out to be a N pole and the top a S pole (reversed in southern hemisphere). No matter how the strip is turned, that edge which is at the top is S and that at the bottom N.

The metal is magnetised by induction by the Earth's magnetic field, the vertical component of which is directed downwards.

The Mumetal screen used round some oscilloscope demonstration tubes can be used.

Experiment 13.19 (a) The domains with N poles directed downwards grow at the expense of those with S poles directed downwards and so the lower end of the nail will become a N and the upper end a S pole.

The nail becomes a permanent, as opposed to an induced, temporary magnet.

As in Britain the vertical component of the Earth's magnetic field is stronger than the horizontal component, this is a more effective way of making the nail into a magnet than hammering it when it is lying horizontally in the meridian.

The most effective position of the nail would be in the direction

of the Earth's field, e.g. in the meridian and inclined, in this country at about 70° to the horizontal.

(b) No comment is needed.

ANSWERS TO QUESTIONS

1. No.

2. See Experiment 2.14.

3-4. The field 'disappears'. It may not become zero, but it will almost certainly become too small to be detected. This is not because each filing loses its magnetism but because the filings are so mixed up that it is extremely unlikely that there is any resultant polarity.

5. South.

6. Yes!

7. The applied heat energy will produce a rise in temperature, i.e. an increase in the mean kinetic energy of the particles in the rod. The increased velocity of agitation will lead to the loss of the ordered arrangement of the atomic magnets.

8. Answers might include the following:

(a) In the loudspeaker of a transistor radio.

(b) On either side of the coil of a moving coil ammeter or voltmeter.

(c) In loudspeaker and focussing units of television sets.

(d) In the mouthpiece of telephone hand sets.

(e) In the strip round the door of refrigerator or cupboard.

(f) To reset the indicators of maximum and minimum thermometers.

9. A few suggestions: in some electric motors and dynamos (e.g. a bicycle dynamo), in electric guitars, in record player pick-up heads, in toys and in door catches.

10.

(a) Suppose the N pole of the magnet approaches the nail; the end of the nail nearer to the magnet becomes a S pole and the other end a N pole, by induction. Attraction is due to the influence of the N pole of the magnet and the S pole of the nail on each other, the other forces between pairs of poles being relatively small.

(b) The block is magnetised by the compass, by induction. The pole of the compass which is nearer the iron when the latter is brought up has more effect than the other pole and induces an opposite pole in the nearest part of the iron block. The resulting attraction makes the compass turn so that it points directly to the block.

11. A line of force or field line.

12. The results would have been similar but the S pole would have pointed downwards.

13. N in the northern hemisphere and S in the southern hemisphere.

14 Electro-Magnetism (pp. 151-159)

Introduction

Experiment 14.1 establishes that the field of a solenoid is similar to that of a bar magnet. Study of the electromagnet and the factors which influence its strength follows in Experiment 14.2. Experiment 14.3, which could be omitted if time were short, will help the pupil to understand what is happening in the core of the electro-magnet.

The use of a solenoid in magnetising and demagnetising is illustrated in Experiments 14.4 and 14.5, both of which are worth doing for the physics involved.

Experiment 14.6, which can be done at home, leads up to the current balance which is investigated in Experiment 14.7 or Demonstration 14.8, preferably the former.

Force on a conductor can be studied in one or more of Experiments 14.9, 14.10, 14.11 (*a*) and 14.11 (*b*); the simplest are probably 14.9 and 14.11 (*a*).

These lead to the electric motor. Experiment 14.12 is not essential, and the apparatus of Demonstration 12.5 provides a good introduction. The motor kit mentioned at the end of Experiment 14.13 would be best assembled at home.

Experiment 14.14 is concerned with electro-magnetic induction and should be attempted. Experiment 14.15 is probably more useful as a demonstration and will serve to consolidate what the pupils have learned in Experiment 14.14.

The dynamo is studied in the last three Experiments, 14.16 and 14.17 linking energy output and input, and 14.18 dealing with the factors which affect the output of a simple alternator.

The Westminster kit (N.92) is particularly useful for the work of this chapter.

Experimental Work

Experiment 14.1. The field resembles that of a bar magnet.

The gauge of wire and the number of turns is not critical, but obviously the resistance of the coil decides the size of the current drawn from the accumulator.

The wire can be wound on a cylindrical former of fairly small diameter. As the field inside the solenoid is to be investigated, it must be arranged that pupils can see between the turns. The cylindrical former, unless made of transparent material, should of course be removed.

Experiment 14.2.

(a) One end of the solenoid is attracted by one pole of the magnet and repelled by the other pole. The forces are unlikely to be strong.

(b) The forces are much stronger.

(c) The lifting power of the electromagnet can be increased by (i) increasing the current, (ii) increasing the number of turns on the nail.

In constructing the solenoid for (a) and (b) it is important to be able to re-insert the iron bar easily. For this reason, plastic-covered wire is preferable to d.c.c. wire, although the latter is effective if wound on a former, e.g. an old thermometer case, into which the iron bar will go.

The aluminium tape suspension should be as long as is convenient; the longer it is, the more easily the solenoid can be turned.

Experiment 14.3. The nails are magnetised with like poles opposite each other and so repel each other.

The movement of the nails can be increased by lengthening the threads by which they are tied together. A simple satisfactory method of suspension is by separate threads, the upper ends held together in the hand.

A former of diameter about 2 in is suitable for the coil.

Demonstration 14.4. Using direct current, the knitting needle is found to be magnetised and repetition using different needles or the original needle demagnetised produces a magnet each time. The end of the needle nearer a given end of the solenoid always becomes the same pole.

When alternating current is used, the needle is again found to be magnetised, but repetition shows that there is no definite polarity associated with a given end of the solenoid. The polarity of the needle depends on the direction of the current in the coil at the instant it is switched off; and this decides the final direction of the magnetising field inside the solenoid.

The solenoid made for Experiment 14.2 can be used.

Demonstration 14.5. (a) and (b) In each method, the magnetising force and hence the polarity of the needle alternates as the current alternates, but the strength of the magnetising force is gradually reduced, eventually becoming so small that no resultant polarity can be detected in the needle, i.e. it is demagnetised.

Again, the coil made for Experiment 14.2 will prove satisfactory, provided a low voltage alternating supply capable of giving at least two or three amps is available; it should not be connected directly to the mains.

Experiment 14.6. The nail is magnetised by the coil, which is itself an electromagnet, and is attracted by it.

To be able to carry out the experiment at home, pupils will probably have to be given wire and possibly something on which to wind it. A length of four or five metres of 24 s.w.g. copper can be wound onto a short length of thermometer case to make a coil which will operate a cardboard signal using a 1.5 V cell (a 4.5 V battery is, of course, more effective). The wire should be wound so that the coil has several layers.

The fulcrum of the cardboard signal should be positioned so that a small force only is needed to pull down the nail.

Experiment 14.7. If the balance tips the wrong way, either the current or the magnet should be reversed.

As the resistance of each bulb (about $12\ \Omega$) is much greater than the resistance of the rest of the circuit, the approximate resistance of the circuit with 1, 2, 3 and 4 bulbs in position is 12, 6, 4 and $3\ \Omega$ respectively. Therefore the currents are in the ratio $\frac{1}{12} : \frac{1}{6} : \frac{1}{4} : \frac{1}{3}$, i.e. 1 : 2 : 3 : 4.

The graph of force against current should be a straight line through the origin, showing that the force is proportional to the current.

Many pupils by the time they reach this stage are capable of using an ammeter and rheostat in place of the four bulbs.

Demonstration 14.8. No comment is needed.

Experiment 14.9. The foil is forced down when the current is switched on. When the current is reversed the foil is forced up.

The downward movement of the foil should be obvious despite the initial downward sag due to its weight, but if it is not, it may be found more satisfactory to fix the tape vertically, say to two wooden clamps at top and bottom of the upright of a burette stand, and to bring up the magnet, supported on a wooden block, so that its pole pieces are on either side of the foil. When the current is switched on the sideways movement of the foil will be easily observed.

Experiment 14.10. Suppose the current is flowing down from the wheel into the mercury. The force on the wheel will then be towards the battery in Fig. 324 and the wheel will rotate in an anticlockwise direction, the force being maintained as each 'spoke' of the wheel in turn dips into the mercury and so becomes the current carrier.

With a strong pair of bar magnets or a strong horseshoe magnet, and a large current, the rate of rotation of the wheel can be high

enough to cause a spray of mercury. This can be dangerous if teacher or pupils are in line with the wheel and it is advisable to use the apparatus with a transparent cover, e.g. a plastic lunch box, over it.

Experiment 14.11.

(a) The field lines, current through rod and direction of motion of rod are mutually perpendicular. To find the direction of motion of the conductor in a given situation the method illustrated in Fig. 327 can be used.

Reversing the current reverses the direction of motion.

The rod and rails may be of any good conductor. Fig. 325 suggests that the rails are directly between the poles of the magnet, in which case, particularly if the rod is light, the force on the rails when current flows through the parts to the right of the rod may be enough to move them. In case of difficulty, a long rod can be used, with each rail well to the side of the magnet.

The Westminster Kit (N.92) is ideal for a variant of this experiment.

(b) The magnets should be fairly close together.

Here is an opportunity to recall that an unbalanced force produces acceleration.

Experiment 14.12. The flow of ions between centre and edge of the dish constitutes a current. The two forces: on positive ions moving one way and on negative ions moving the other way, are in the same direction and so the liquid is pushed to one side. Circulation follows.

While it is easy to bend the end of one of the pieces of copper wire so that it hangs over the end of the dish and dips into the solution, it is not so easy to hold the other wire in the centre of the dish. Using fairly thick wire and bending it through a clamp above the dish, or clamping a copper rod in position are both satisfactory.

Powdered chalk can be used in place of lycopodium; rub a stick of chalk on sandpaper held above the solution.

A metal disc with current flowing through it via connections at axle and edge, will rotate the poles of the magnet as in Barlow's wheel (Experiment 14.10). The metal used should be a non-magnetic conductor such as copper or aluminium.

Experiment 14.13. The wires should be held lightly against the commutator, diametrically opposite each other. A similar motor can be built from the Westminster Kit (N.92).

Experiment 14.14. Two suitable experiments are as follows (in each of them a meter of full-scale deflection equal to a few milliamps is quite adequate):

(a) Connect the ends of a long loop of copper wire to the meter and move the middle of the loop quickly between the poles of a strong horseshoe magnet. If a centre zero meter is used, the effect of direction of motion of the wire on direction of current can be demonstrated. The size of the induced current depends on the speed at which the conductor is moved through the field.

(b) Simply connect the meter to the ends of the coil. The strength of the current depends on the speed at which the magnet is thrust into the coil (it also depends on the number of turns of the coil). The direction of current can be changed by reversing the magnet. It is also changed when the magnet, without being reversed, is moved out of the coil (see Experiment 14.15).

Experiment 14.15. As the magnet vibrates, an alternating current is produced in the coil.

It may be considered simpler to allow the magnet to vibrate on the end of a coil spring held above the coil. The frequency can be varied by using different springs.

Connecting a C.R.O. across the coil in place of, or as well as, the galvanometer is interesting. The up and down movement of the spot clearly indicates the alternating nature of the induced e.m.f.

Experiment 14.16. As the speed of rotation is increased, the output voltage is increased.

Demonstration 14.17. When energy is taken from the dynamo to light the bulb, it is harder to turn and a drop in speed can be detected. By Lenz's law, the current in the armature opposes the force producing it.

Experiment 14.18. With the keeper in position, the field of the magnet is mainly confined to the keeper and so there is little or no linkage with the turns of the coil. The effect is then negligible.

The size of the e.m.f. is affected by

- (a) the rate of rotation of the magnet,
- (b) the number of turns of the coil,
- (c) the strength of the magnetic field (can be varied by changing the distance between the magnet and the coils; washers can be inserted between the magnet and its axle support).

Pupils should be able to show effect of (a) and (c).

The connection of the coils to each other is important. At any instant the polarity of the ends of the coils nearer to the magnet will be opposite and so the directions of the induced e.m.f.'s. in the coils will be opposite. In order that they reinforce each other and produce a current, the direction of winding of each coil should be opposite.

ANSWERS TO QUESTIONS

1. The lines of force are circles with the wire as centre. The wire is perpendicular to the plane of each circle. If the electrons are flowing towards the observer, the direction of each line of force is clockwise (see p. 138).

2. A North pole.

3. The lines of force are parallel and relatively close together, i.e. the field is stronger inside the solenoid than at any point outside it.

4. The armature and contact are originally touching so that when the switch is closed the circuit is completed and a current flows, activating the electro-magnet. The latter attracts the armature, which moves towards it, breaking the circuit and switching off the electro-magnet. The armature, being no longer attracted, is pulled back by the spring, touches the contact and the whole process starts again. The rapid to and fro movement of the armature between magnet and contact produces the buzzer noise.

5. Yes (Newton III).

6. The forces on the coil are equal and opposite and in the same straight line, so that the resultant force is zero; there is no turning effect.

7. This can be done if the current in the coil is reversed.

8. If some device could be attached to the coil so that each time it arrived at a position such as (c) in Fig. 329, when its plane was perpendicular to the field, the current was reversed, it would continue to rotate.

A commutator is required.

9. 50 c/s. This is the nominal value; the actual value may be slightly different. When, for example, the demand for power exceeds the supply and cuts have to be made, the frequency may drop several cycles below 50.

